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DOT/FAA/CT-85/26
TR-85-F-11

FAA TECHNICAL CENTER
Atlantic City Airport
N.J. 08405



# Summary of Artificial and Natural Icing Tests Conducted on U.S. Army Aircraft from 1974 to 1985

Harry W. Chambers
John Y. Adams



July 1986

Final Report

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U.S. Department of Transportation
**Federal Aviation Administration**

US ARMY
AVIATION
SYSTEMS COMMAND

# NOTICE

**Technical Report Documentation Page**

| 1. Report No. | 2. Government Accession No. | 3. Recipient's Catalog No. |
|---|---|---|
| DOT/FAA/CT-85/26 (TR-85-F-11) | AD-A173 764 | |

| 4. Title and Subtitle | 5. Report Date |
|---|---|
| Summary of Artificial and Natural Icing Tests Conducted on U.S. Army Aircraft from 1974 to 1985 | July 1986 |
| | 6. Performing Organization Code: AMSAV-E |
| 7. Author(s): Harry W. Chambers and John Y. Adams | 8. Performing Organization Report No.: TR-85-F-11 |
| 9. Performing Organization Name and Address: U.S. Army Aviation Systems Command, ATTN: AVSAV-E, 4300 Goodfellow Boulevard, St. Louis, MO 63120-1798 | 10. Work Unit No. (TRAIS) |
| | 11. Contract or Grant No.: DTFA03-80-A-00199 |
| 12. Sponsoring Agency Name and Address: U.S. Department of Transportation, Federal Aviation Administration Technical Center, Atlantic City Airport, NJ 08405 | 13. Type of Report and Period Covered: Final Summary Report 1974-1985 |
| | 14. Sponsoring Agency Code |

15. Supplementary Notes

16. Abstract

The U.S. Army Aviation Systems Command (USAAVSCOM) conducts airworthiness qualification testing on aircraft under artificial and natural icing conditions. A JCH-47C helicopter with a Helicopter Icing Spray System (HISS) installed is used for generating a simulated natural icing environment. The artificial icing tests are followed by natural icing tests to assure a wide variety of flight conditions are tested and to verify artificial icing test results. The JCH-47C/HISS has been used since 1974 for conducting research, engineering, development, and qualification testing for U.S. Army, ~~U.S.~~ Navy, NASA, and various contractor aircraft. The USAAVSCOM has compiled an extensive artificial and natural icing test data base. ~~The~~ data is summarized in this report. Detailed time histories of selected natural icing encounters have been provided under separate cover to the Federal Aviation Administration (FAA).

This report documents unclassified U.S. Army, other U.S. Government agencies, and commercial icing test programs. Also discussed is the use of deice and anti-ice systems; the impact of ice accretion and shedding characteristics, performance considerations, stability and control, and vibration characteristics; and the cloud parameters measurement equipment and test aircraft instrumentation used for documenting test data. The test methodology and requirements used for qualifying aircraft for flight into icing conditions, instrumentation, and special equipment are summarized, and the details for test conducted are contained in the references. The report documents, in part, 14 years of U.S. Army experience in conducting in-flight aircraft icing tests, and is provided to the FAA under interagency agreement in the preparation of manuals and other documents relative to the certification of civil aircraft as appropriate.

| 17. Key Words | 18. Distribution Statement |
|---|---|
| Helicopter Icing, Certification, Aircraft Icing, Liquid Water Content, Supercooled Clouds, Airworthiness Qualification | Document is available to the U.S. public through the National Technical Information Service, Springfield, Virginia 22161 |

| 19. Security Classif. (of this report) | 20. Security Classif. (of this page) | 21. No. of Pages | 22. Price |
|---|---|---|---|
| Unclassified | Unclassified | 206 | |

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

# PREFACE

1. This report summarizes U.S. Armv icing tests in accordance with requirements of Interagency Agreement No. DTFA03-80-A-00199 between the Federal Aviation Administration (FAA) and the U.S. Army Aviation Systems Command (USAAVSCOM) (formerly the U.S. Army Aviation Research and Development Command), St. Louis, Missouri.

2. This report covers the U.S. Army icing research, development, and engineering testing from 1974 through 1984. Technical monitors of the project for the FAA were Richard I. Adams and Larry Hackler.

3. The report was prepared for the FAA by Mr. H. W. Chambers and Mr. J. Y. Adams, USAAVSCOM. Major technical contributions were made by the U.S. Army Aviation Engineering Flight Activity (USAAEFA), Edwards Air Force Base, California. Principal contributors were COL A. Todd, LTC C. Frankenberger, LTC G. Wilson, MAJ L. Hanks, Mr. R. Woratschek, and Mr. D. Belte. The documentation contained in the report was obtained from test plans and test reports relative to the actual flight test projects conducted by USAAEFA and extensive coordination meetings between USAAVSCOM, USAAEFA, and the FAA representativs. The USAAEFA contributions are based on the outstanding and professional achievements in planning, conducting and documenting research, development, and engineering icing test projects on aviation systems and material. While most of the projects are related to the U.S. Army Airworthiness Qualification process, most results are directly applicable to the FAA Certification Process. Several of the projects resulted in developing new techniques and hardware relative to improving the capability for qualifying/certifying aricraft for flight into known icing conditions.

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# EXECUTIVE SUMMARY

This report summarizes U.S. Army aircraft icing tests from 1974 to 1985. The U.S. Army Aviation Systems Command (USAAVSCOM) is responsible for aircraft icing airworthiness qualification testing of Army aircraft in which both artificial and natural icing conditions are employed. The artificial icing conditions are generated by using a Helicopter Icing Spray System (HISS) installed in a JCH-47C helicopter. The natural icing conditions are obtained by establishing a temporary base of operations in an area that provides conditions conducive to the icing desired. Areas used have included Alaska; Minneapolis-St. Paul, Minnesota; and Deluth, Minnesota. Aircraft are normally flown in the HISS artificial cloud, and then the results are substantiated in natural conditions.

The ability of the HISS to produce icing conditions that approach conditions found in nature has improved greatly since 1974. The HISS has the ability to produce liquid water contents (LWC) from 0 to 1.3 $gm/m^3$, and mean volume diameters (MVD) from 17 m to 65 m. The dimensions of the artificial cloud are approximately 8 feet high and 36 feet wide: however, cloud characteristics may vary depending upon airspeed, position within the cloud, temperature, and relative humidity.

Differences in Army qualification and the FAA certification requirements are mandated by goals and objectives. A goal of the U.S. Army aircraft icing qualification process is to provide increased staying power on the modern battlefield during adverse weather conditions. Whereas, the objective of FAA aircraft icing certification is to ensure that civil aircraft can operate safely in known icing conditions. These differences form the basis for differences in the Army's qualification process and the FAA's certification process.

For example, the U.S. Army qualifies aircraft for limited operational icing envelopes based upon meteorological conditions. Whereas, the FAA requires that helicopter manufacturers seeking approval of helicopters for flight into known icing be certified through the full icing envelope provided in Federal Aviation Regulation (FAR) 25, Appendix C, or to one of the altitude limited criteria presented in Advisory Circular (AC) 29-2. Icing qualification tests on aircraft, such as the U-21A, CH-47C, and UH-60A, are described and include discussions of ice protection systems, ice accretion and shedding characteristics, and stability and control.

# INTRODUCTION

## BACKGROUND

1. In order to increase the staying power of U.S. Army Aviation on the modern battlefield during adverse weather conditions, most recent helicopter developments have design requirements to operate in moderate icing conditions. Older U.S. Army aircraft have varying degrees of ice protection, but were not developed with the intent to operate continuously in an icing environment. Since the design criteria necessary for aircraft operations in natural icing conditions were uncertain, in-flight icing tests were required to substantiate airworthiness.

2. Although natural icing flight tests are required, conducting tests in a simulated icing environment presented several advantages over conducting natural icing tests only. The use of a simulated icing environment would provide a margin of safety because the test aircraft could enter and exit the environment at will, a buildup flight test program leading to greater icing severity levels could be adopted, and most significantly, the test time could be reduced by years, thereby expediting critical operational deployment. As a result of these considerations, the U.S. Army Aviation Systems Command (USAAVSCOM) developed during 1972/1973 a Helicopter Icing Spray System (HISS) designed to produce an artificial supercooled cloud which would create a simulated natural icing environment for the conduct of artificial icing tests. The HISS was designed into a CH-47C helicopter, and assigned to the U.S. Army Aviation Engineering Flight Activity (USAAEFA) located at Edwards Air Force Base, California. The HISS has been employed in the conduct of icing tests on a yearly basis and has undergone several improvement programs since its conception. The HISS has been used extensively to support not only the U.S. Army icing tests, but also the requirements of other Government and civilian agencies such as the Federal Aviation Administration (FAA), the National Aeronautics and Space Administration (NASA), commercial contractors, the U.S. Navy and the U.S. Air Force relative to research, development, qualification, and certification efforts.

3. The FAA has been involved in research and development efforts to form a basis for establishing helicopter icing certification standards. FAA interest in U.S. Army icing qualification efforts and the U.S. Army's extensive experience gained in the development of a unique icing test capability led to the signing in 1978 of the first of several Interagency Agreements (IA) between the FAA and USAAVSCOM. The information contained in this report documents the U.S. Army qualification efforts and experience and provides an excellent basis for the FAA in establishing certification requirements for civil aircraft. The report compiles for the first time in a single document the detailed experience of U.S. Army aircraft icing tests and satisfies the basic requirements of the Interagency Agreements.

## OBJECTIVES

The objectives of this report are to document the requirements of the FAA/U.S. Army IA number DTFA03-80-A-00199 relative to U.S. Army aircraft icing tests as follows:

a. The HISS development and improvement program.

b. Definition of the U.S. Army's airworthiness qualification procedures for qualifying aircraft for flight into icing conditions.

c. Summary of natural meteorological icing test data.

d. Summary of the results of ice phobics flight testing.

e. Address specific questions raised in the FAA/U.S. Army IA.

## SCOPE

1. This report compiles and documents the results from both artificial and natural icing tests conducted by USAAEFA since 1974. The report documents testing through the 1984 icing test season and also details the HISS development and improvement program. The modification and use of a JU-21A aircraft to obtain natural and artificial cloud parameters is documented in the report since the JU-21A is an essential test support capability for the conduct of icing tests.

2. The general approach to preparing this summary report consisted of condensing each USAAEFA test report into a format that included a brief description of the test aircraft and a discussion of the results and conclusions reported.

3. The U.S. Army's icing qualification procedures and requirements are discussed in this summary report. Icing severity levels are used throughout and are defined quantitatively in terms of liquid water content (LWC) and grams per cubic meter ($gm/m^3$) of water as follows. Additionally, icing test temperatures do not go lower than minus 20 degrees centigrade (-20°C) due to HISS limitations and the improbability of obtaining any significant ice accretion below 20°C. The basis for establishing the U.S. Army's qualification requirements are contained in USAAMRDL-TR-75-34A (reference A-1, Appendix A).

Trace icing: 0-.15 $gm/m^3$

Light icing: .15-0.5 $gm/m^3$

Moderate icing: 0.5-1.0 $gm/m^3$

Heavy icing: above 1.0 $gm/m^3$

## TEST AIRCRAFT

A variety of aircraft, some with sophisticated ice protection systems and others with very little ice protection, were tested per the test conditions contained in Appendix B, and are listed below. Details of the aircraft

configurations, including instrumentation and special equipment for ice protection, are contained in Appendix C.

| U.S. Army Helicopters | Civilian Helicopters | U.S. Army Fixed Wing |
|---|---|---|
| AH-1G | BHT 214ST | OV-1D |
| AH-1Q | BHT 412 | U-21 |
| CH-47 | Sikorsky SA-76 | |
| YCH-47D | | |
| UH-1H | | |
| JUH-1H | | |
| YAH-64 | | |
| UH-60A | | |
| YEH-60A | | |
| YUH-60A | | |
| YUH-61 | | |

## RESULTS AND DISCUSSION

### GENERAL

The U.S. Army method of qualifying aircraft for flight in icing conditions relies primarily on a simulated icing environment using the HISS to produce an artificial supercooled cloud and then conducting natural icing tests to substantiate the artificial icing test results. The natural icing tests are flown using typical mission profiles to evaluate ice accretion and shedding characteristics under natrual icing conditions and expanded flight conditions such as climb, cruise, descent, maneuvering, and approach. Test methodology and operational problems attributed to flight in icing conditions are discussed. Anti/deicing systems and icing instrumentation were evaluated during icing tests and such evaluations are discussed in the individual report sections of this summary report.

### HISS DEVELOPMENT AND IMPROVEMENT

1. The U.S. Army began development of a HISS in 1972 and it was made operational in 1974 for the conduct of artificial icing tests in a simulated icing environment. In-flight icing simulation provided several advantages over natural icing testing, such as greater availability of icing test conditions, and the ability to control variables, such as LWC and temperature. The total test program could be shortened in that the test team would not have to rely on specific natural icing conditions to occur. Furthermore, since the test aircraft could enter and exit the icing cloud at will, the overall safety of a test program was significantly improved.

2. In 1972 the U.S. Army, under contract to the All American Engineering Company (AAEC), modified a CH-47C aircraft with substantial structural and system changes to accept a HISS. This system consisted of an internally mounted 1,800 gallon water tank and an external spray boom assembly suspended beneath the CH-47C from a cross tube through the cargo compartment. The boom assembly could be lowered and raised by hydraulic actuators which rotate the cross tube. Temperature and humidity was measured by onboard instrumentation. A 150-to-250 foot standoff distance to the test aircraft was determined to be optimum and could be maintained with the assistance of an aft-facing radar altimeter mounted in the rear of the HISS. Aircraft engine bleed air was used to atomize water which was pumped to nozzles located in the spray boom, thus generating an artificial icing cloud. Flight test airspeeds were nominally 90 to 120 knots true airspeed (KTAS).

3. The original HISS configuration had a single spray bar suspended 15 feet beneath the aircraft and consisted of three 75-foot long sections. This configuration had the following shortcomings:

a. The single spray bar produced a cloud of insufficient depth to simultaneously immerse the fuselage and main rotor of most Army helicopters.

b. Rotor down wash behind the HISS placed the test aircraft in an equivalent 500 to 1,000 foot per minute (ft/min) rate of descent condition which required additional power to maintain level flight.

c. LWC was not uniform within the icing cloud and water droplet size and distribution was not completely representative of that encountered in natural icing.

4. The first major modification to the original HISS design occurred in 1975 when the 75-foot wide single bar was replaced with a 60-foot wide dual trapeze assembly. The center section was lengthened two feet (ft) and lowered four ft below the original, and a second bar was installed five ft beneath the first. The outriggers were reduced to 17.6 ft long and swept back 20 degrees and angled downward ten degrees. The nozzle locations were rearranged to increase cloud uniformity. Although some of the original problems were alleviated, they were not totally eliminated. An additional problem, the formation of ice, termed "popsicles," near the various nozzles occurred when sprayed water froze on the boom at temperatures below -20°C or when warm bleed air failed to reach the nozzles at temperatures below freezing.

5. In order to quantify the HISS cloud, as well as to compare it to a natural icing cloud, several measurement programs were initiated. The main parameters of a supercooled cloud icing environment are temperature, LWC, droplet size, and distribution. LWC, droplet size, and distribution are the more important HISS parameters as they determine the desired cloud composition. The droplet median volume diameter (MVD) is used to define the distribution of droplets within a cloud. Stratus clouds, for example, have MVDs in the 10 to 30 micron (μm) range. The first quantitative measurement of the HISS cloud, using a gelatin coated glass slide droplet collector, found MVDs of 140 μm. Tests conducted after the dual boom configurations were incorporated using a cloud particle spectrometer found particles from 12 μm to 200 μm including drops larger than 300 μm. A more thorough survey of the HISS cloud was conducted in 1979 using laser nephelometers to measure droplet size and distribution. The survey also attempted to correlate cloud characteristics with control variables, e.g., water flowrate, position in the cloud, and distance to the test aircraft. Measurements again showed large variations in LWC and MVD within the horizontal and vertical position in the cloud. Droplet MVDs near the top of the spray cloud ranged from 50 μm to 100 μm and from 200 μm to 300 μm at the bottom.

6. Although the HISS was still a valid icing test tool, it was not producing a spray cloud representative of a supercooled stratus cloud. Many variables were considered and the problem seemed to center on the type of nozzle being used and the available air pressure. An improvement program was begun in 1979, under contract with Boeing Vertol, to identify and provide improvements to the HISS. Approximately 17 different nozzles were evaluated in the NASA/Lewis Icing Research Tunnel (IRT). Some of the conclusions and results of this evaluation were:

a. The original AAE nozzle produced droplet MVDs ranging from 200 to 300 μm, an undesireable characteristic.

b. Orientation of the nozzles perpendicular to the airstream provided the best spray.

c. A "rooster tail" effect, the separation of large and small droplets, was very evident in the AAE nozzle spray pattern.

d. Water droplets in the IRT did not become supercooled in the short distance from the nozzles to the measurement probes as they do behind the HISS; however, this was concluded to have minimum measurable impact on the accuracy of the cloud LWC and MVD characteristics.

e. There was a significant cooling of the water in the boom sections and the system had to be purged with hot bleed air just prior to the start of water flow to prevent freezing; however, this was an IRT problem and does not present a problem in the HISS since warm air is continually applied to the nozzles on the boom through a pressurized system.

f. Of all the nozzles tested, the Sonicore nozzle was favored because it produced an acceptable droplet MVD approaching that measured in the natural supercooled cloud.

g. A typical natural icing cloud has a 100 percent relative humidity. This high humidity cannot be duplicated in an artificial cloud since the cloud is altered by the ambient relative humidity due to evaporation effects. For example, if a test is conducted on a day when the ambient relative humidity is 70 percent, a 20 μm drop will lose 60 percent of LWC at 0°C and 20 percent at -20°C; therefore, HISS flowrates have to be increased to compensate for evaporation. For this reason, HISS tests are preferably conducted when conditions are overcast and high humidity exists.

7. Another problem associated with artificial testing was the interference of the icing cloud by the downwash generated by the HISS rotors. Photographic coverage of smoke bomb tests indicated:

a. The distance behind the spray bar at which the rotor tip vortex disturbance intersected the central portion of the cloud was approximately 250 ft at 80 KTAS and 90 ft at 100 KTAS. The flow field behind the center sections was relatively undisturbed forward of this point.

b. The rotor tip vortices caused the rollup of outer portions of the spray from the outriggers.

8. As a result of the NASA/Lewis IRT testing, the AAE nozzles were replaced by Sonicore nozzles in 1980. For the initial flights, 160 Sonicore nozzles were installed, but testing revealed that there was insufficient pressure available to produce a suitable cloud. A decision was made to isolate the outrigger sections and use 97 nozzles installed on the center sections only to increase the pressure to the remaining nozzles. This configuration produced the most satisfactory supercooled cloud having the necessary droplet size distribution to adequately approximate the natural cloud for test purposes. Several problems including periods of freezing of nozzles and nozzle blockage due to residual water tank debris occurred. The increased weight of the boom assembly, because of the Sonicore nozzle installation, aggravated boom dynamics problems and increased aircraft sensitivity to turbulence; however, these problems were acceptable in lieu of the improved cloud characteristics achieved.

9. In 1980, flight tests were conducted to check boom dynamics and establish a flight envelope for the final boom configuration. Boom stresses

were satisfactory in the 97 and 160 nozzle configuration with the boom DOWN at airspeed to 140 KTAS and to 146 KTAS with the boom UP.

10. In 1981, an auxiliary power unit (APU) was installed in the HISS to improve airflow to the Sonicore nozzles. Pressure was still insufficient to fill all of the 160 usable nozzle locations. Pressure was sufficient to use 97 nozzle positions on the center boom only and still better droplet atomization and acceptable cloud characteristics at higher flow rates under high relative humidity conditions.

11. In 1982, a program was undertaken to eliminate numerous air and water leaks that degraded HISS operations in earlier test seasons. All the boom external hoses were replaced, and the round water manifolds and plastic lines were replaced by T section manifolds and stainless steel lines. Boom dynamics and stresses were checked again and found to be acceptable.

12. The current 1984 HISS configuration has the following operating characteristics:

| | |
|---|---|
| LWC | 0 to 1.3 gm/m$^3$ |
| MVD within the spray cloud at 180 foot HISS boom standoff distance from the HISS boom | 17 μm to 30 μm at the top of cloud<br>20 μm to 65 μm at the bottom of cloud |
| Test Temperature Range | 0°C to -20°C |
| Density Altitude Range | 0 to 12,000 ft |
| Airspeed Range | 80 to 130 KTAS |
| Cloud Depth | 8 ft |
| Cloud Width | 36 ft |

13. USAAVSCOM has initiated action to design, fabricate, install, and qualify through flight testing an improved HISS which will be palletized and installed in a JCH-47D helicopter. Even with all the significant improvements that were incorporated into the JCH-47C HISS configuration, there are still shortcomings in the production of the artificial cloud, as previously discussed. Basically, the width and depth of the HISS cloud needs to be increased to allow complete immersion of a test helicopter and the generation and control of the cloud needs to be improved to more closely approximate the natural supercooled cloud. Additionally, the HISS needs to be a palletized system easily removed and installed in another aircraft to preclude lost test time in the event of a major mechanical failure of the aircraft. The current JCH-47C HISS has extensive structural and subsystem interfacing (bleed air, hydraulic and electrical) modifications which require it be strictly dedicated for icing tests. The Boeing Vertol Company was contracted with by USAAVSCOM to perform a design analysis to determine the design approach for an improved HISS, as well as the best type aircraft required to carry the HISS in order to achieve the following spray cloud design goals.

| | |
|---|---|
| LWC | 0 to 3.0 gm/m$^3$ |
| MVD | 10μm to 50μm |
| Test Temperature Range | 0°C to -30°C |
| Altitude Range (density altitude) | 0 to 12,000 ft |
| Airspeed Range | 60 to 150 KTAS |
| Cloud Depth | 25 ft |
| Cloud Width | 75 ft |
| Cloud Spray Endurance at 1.0 gm/m$^3$ continuous | 1 hour |
| Aircraft Endurance | 2 hours |

14. The Boeing Vertol Company submitted the design analysis report for the HISS Improvement Program (Reference A-2, Appendix A) in 1984. The report recommended using the CH-47D as the aircraft for carrying the palletized HISS and the following design goals:

| | |
|---|---|
| LWC | 0 to 2.0 gm/m$^3$ |
| MVD | 15 μm to 50 μm |
| Test Temperature Range | 0°C to -20°C |
| Altitude Range (density altitude) | 0 to 12,000 ft |
| Airspeed Range | 0 to 130 KTAS |
| Cloud Depth | 15 feet |
| Cloud Width | 55 feet |
| Cloud Spray Endurance at 1.0 gm/m$^3$ continuous at 120 KIAS | 0.53 hours |
| Aircraft Endurance at Above Conditions | 2.0 hours |

15. The design analysis report submitted by The Boeing Vertol Company will be used as the basis for the new improved palletized JCH-47D/HISS. Current plans are to award a contract in FY 1986 for the design, fabrication, installation and qualification of the palletized HISS in the JCH-47D. If funding for the efforts proceeds as expected, then a significantly improved JCH-47D/HISS will be available for use in conducting the icing qualification/FAA certification tests during the 1988/1989 icing season. With the new design goals, the JCH-47D/HISS will be able to produce a supercooled cloud more closely approximating natural, as well as high LWCs, consistent with the requirements established in FAA final reports DOT/FAA/CT-83/22 (Reference A-3, Appendix A) and DOT/FAA/CT-83-21 (NRL Report

8738) (Reference A-4, Appendix A). These reports provide a new data base of supercooled cloud variables for altitude up to 10,000 feet AGL and a new characterization of supercooled clouds below 10,000 feet AGL for certification requirements. The improved JCH-47D/HISS capability will be adequate for the qualification of U.S. Army helicopters. Additionally, the JCH-47D/HISS capability will provide an in-flight icing capability which could be used to meet certification requirements for the extreme temperature and LWC supercooled cloud conditions specified in FAA Advisory Circular 29-2, Certification of Transport Category Rotorcraft (Reference A-5 Appendix A).

## FAA CERTIFICATION AND US ARMY QUALIFICATION ICING CRITERIA

1. The FAA has recently been involved in the certification of helicopters for flight in icing conditions, and in particular, establishing the necessary guidance and standards. The FAA requires that helicopter manufacturers seeking approval of helicopters for flight into known icing be certified throughout the full icing envelope provided in FAR 29, Appendix C, or to one of the altitude limited criteria presented in advisory circular AC-29-2.

2. The U.S. Army does qualify aircraft for limited operational icing envelopes based upon meteorological conditions. The rationale being that the crew, with appropriate instrumentation, should continuously monitor these conditions and be prepared to exit the environment when certain prescribed limits are reached. Since 1972, the U.S. Army has used this philosophy safely and there have been no helicopter accidents involving loss of lives, injury, or major damage directly attributable to operations under icing conditions.

3. The existing meteorological design criteria, contained in FAR 25, Appendix C and MIL-E-38453, were established for fixed-winged aircraft and are based upon data acquired in the 1940s and 1950s. In general, the continuous maximum and the intermediate maximum icing conditions (cumulus clouds) represent 99.9 percentile severity levels. Furthermore for supercooled droplets which represent the normal icing situations, helicopters should be designed to operate at a minimum temperature of -20°C instead of -30°C because of the lower altitudes (below 10,000 ft) at which these aircraft operate. The MVD of supercooled droplets lies in the range of 10 μm to 40 μm and in this range, ice accretion is limited to the leading edge of rotor blades and other aerodynamic surfaces (to approximately 20 percent chord), windshields, the nose region of the fuselage, and other surfaces of the aircraft. The current icing design criteria for the continuous and intermediate icing conditions, adopted by the U.S. Army, are represented in USAAMRDL-TR-75-34A.

4. Freezing rain, a much more severe condition, encompasses supercooled water droplet diameters in the hundreds of microns. It has not been observed at temperatures below -10°C. Because of the large droplet diameters, ice accretion extends over a much larger area of the helicopter. Designing for operations in freezing rain imposes weight, performance, and cost penalties which are unacceptable. U.S. Army aircraft are not intentionally operated in freezing rain.

5. Snow criteria have been developed, but snow is not considered to be a problem for aircraft that have been properly designed for flight in icing conditions. There is a potential problem of snow which has accumulated in engine inlets due to melting and then refreezing. This potential source of foreign object damage (FOD) is considered in the design of engine inlets.

6. In order to determine the applicability of these standards to helicopters, the U.S. Army contracted with the Lockheed-California Company to undertake an icing severity analysis. The results of this study are contained in USAAMRDL-TR-75-34A. Essentially, this report concluded that in accordance with U.S. Army Regulation, AR 70-38, Research, Development, Test, and Evaluation of Materiel for Extreme Climatic Conditions, the icing severity criteria levels need not exceed the 99.0 percentile level below 10,000 ft. Furthermore, for supercooled droplets which represent the normal icing situations, helicopters should be designed to operate at a minimum design temperature of -20°C (-9°F) instead of -30°C (-22°F), because of the lower altitudes (below 10,000 ft) at which these aircraft operate. The supercooled droplets lie in the range of 10 - 40 microns. In this range, ice accretion is limited to the leading edge of rotor blades and other aerodynamic surfaces (to approximately 20 percent chord), windshields, the nose region of the fuselage, and other surfaces peculiar to a particular aircraft. The current icing design criteria for the continuous and intermediate icing conditions, adopted by the U.S. Army, are represented in Figure 12 of USAAMRDL-TR-75-34A.

## TEST AIRCRAFT BY ICING SEASON

1. USAAEFA Project No. 77-05, Icing Evaluation, U-21A Airplane with Low Reflective Paint (Reference A-6, Appendix A), 1977 Icing Season.

a. The purpose of this project was to compare the ice accretion and shedding characteristics of a U-21A aircraft painted with low reflective paint with a U-21A aircraft painted with a high gloss (standard) paint. Two aircraft were used in this determination:

(1) Test aircraft: U-21A, S/N 68-18107, painted with low reflective paint (MIL-L-46159).

(2) Standard aircraft: U-21A, S/N 66-18008, painted with the standard high gloss polyurethane (MIL-C-81773).

With the exception of the paint, both aircraft external configurations were essentially the same. Both aircraft were flown in trace, light, and moderate icing conditions with a three (3)-mile separation between the aircraft.

b. Instrumentation and Cloud Measurement Equipment - Instrumentation for this test was limited to the aircraft onboard instrumentation supplemented by a heated total temperature system, in-flight and post flight photography to document the test parameters, and a voice recorder for pilot comments. A visual ice accretion probe was installed on both aircraft to measure the incremental accumulation of ice and determine the icing severity. A list of instrumentations is provided in Appendix C-1.

c. Ice Protection Systems - No special ice protection systems were installed for these tests. The standard U-21A systems were used. These consisted of an electrothermal system for anti-icing and deicing the windshield, pitot tube, stall warning vane, propeller blades, engine air inlet lip boots, and fuel vents. Pneumatic boots are incorporated for deicing the leading edges of the outer wing (outboard of the engine nacelle to 30 inches short of the wing tip) and the vertical and horizontal stabilizers.

d. <u>Ice Accretion and Shedding characteristics</u>

(1) The two aircraft were flown in natural icing conditions with the ice buildup the same for both aircraft. The effectiveness of the deicing boots was largely dependent upon the type of ice to which the aircraft was exposed. In a clear or mixed ice environment, the boots were effective in clearing the ice, while in a rime ice environment of light icing intensity they were not. The engine air inlet lip boots could not prevent ice formations on the inlet and some ice accumulated inside the engine inlet. The landing light was turned on in an attempt to assist in shedding ice after it had built up on the outer wing. This proved to be ineffective during the on cycle of the light (approximately one (1) minute).

(2) The test aircraft had an electrothermal anti-icing system for the windshield while the standard aircraft had only a defrost air system installed. Both systems were effective in keeping the windshield clear of ice; however, the defrost system on the standard aircraft allowed a greater ice buildup than the electrothermal system.

e. <u>Performance</u> - Two airspeeds were evaluated upon initial entry into the icing conditions. At 140 knots calibrated airspeed (KCAS), both aircraft could not maintain level flight with maximum [illegible] when ice accumulated to a thickness of approximately two inches on unprotected surfaces. After activation of the pneumatic boots, the power required to maintain level flight was greatly reduced. At 170 KCAS, with constant power application for level flight, a decrease in airspeed of 20-30 KCAS was noted with an accumulation of 0.5 to 1 inch of ice on the wing leading edge deicer boots. At this same ice accumulation level, 170 KCAS could be maintained if full power were applied to both engines. After activation of the deicing boots the power required for level flight was reduced.

f. <u>Handling Qualities</u> - There were no discernable differences in the handling qualities due to ice accumulation or the effects of the ice accumulation between the two aircraft. It was determined, as a result of these tests, that the U-21A aircraft can be safely flown in trace, light, and moderate icing conditions; however, at a constant power setting, an airspeed loss of 20 to 30 KCAS should be expected with flight in moderate icing conditions regardless of the paint configurations. No differences in ice buildup were noted due to the low reflective paint used on the test aircraft.

2. USAAEFA Project No. 73-04-01, Artificial Icing Tests, CH-47C Helicopter <u>(Reference A-7, Appendix A)</u>, 1974 Icing Season.

a. The Department of the Army requested that first-line Army helicopters be tested for flights in artificial conditions generated by a helicopter icing spray system (HISS). This project was tasked as a result of a request to determine the capability of the CH-47C helicopter to safely operate in an icing environment, to verify the icing limitations presented in the CH-47C Operator's Manual and to evaluate the capabilities of the standard CH-47C anti-ice and installed special equipment. The test aircraft was a standard CH-47C helicopter, S/N 69-17126, and was in the standard configuration except for removal of the cargo mirror, removal of the engine inlet screens and stowage of the cargo hook. The cabin heat and anti-ice systems were on throughout the flights in the icing environment.

b The test aircraft was flown in an icing cloud produced by the HISS. It was determined that the most stable flight condition for the test vehicle was at a standoff distance of approximately 110 feet and all tests were conducted in this region. Prior to entering the ice cloud, the standard aircraft windscreen, engine, pitot tube, and stability augmentation system (SAS) port anti-icing system were activated. The test aircraft was then flown into the spray cloud to accumulate a predetermined amount of ice. The aircraft then exited the cloud and qualitative and quantitative tests were performed. Test conditions are listed in Appendix B-1.

c. Instrumentation and Cloud Measurement Equipment - During this test series, a photo panel, magnetic tape recorder, and portable cassette tape recorder were used to record aircraft performance data. Ice detection equipment, as well as photo documentation, were utilized to record icing data. Specific instrumentation is listed in Appendix C-2.

d. Ice Protection Systems - The standard anti-ice systems of the CH-47C consisting of engine anti-ice, heated pitot tube, SAS yaw port heating and windshield anti-icing systems were evaluated throughout the test program. The standard anti-ice systems operated effectively and without failure. The engine air inlet fairings, engine transmission fairings, and the heated portion of the engine drive shaft remained free of ice at all test conditions. The heated pitot tube remained clear of ice throughout the icing test program. When the windshield anti-ice system was activated five minutes prior to entering the artificial icing environment, as recommended by the Operator's Manual, satisfactory operation was observed and the windshield remained clear of ice. Within the scope of this test, the standard anti-ice systems functioned properly.

e. Ice Accretion and Sheeding Characteristics - The artificial icing test base consisted of a static temperature of -6.0C to -8.5C, with a liquid water content (LWC) of 0.25 through 1.05 gm/m$^3$. Tests at lower temperature were not conducted due to climatic conditions at the test site. Under the conditions tested, ice thickness varied from 1/16 to 1 inch of glime ice. This was visually observed during flight. Symmetrical ice shedding from the rotor system was observed in light to heavy icing at or above a static temperature of -6.5°C and in light icing at -8.5°C. Ice shedding from the rotor system generally remained in the tip path plane, striking succeeding blades of the same rotor or blades of the other rotor system. Ice shedding from the rotor system also impacted on portions of the fuselage.

f. Vibration - Symmetrical ice shedding on the rotor systems insignificantly affected the aircraft vibration levels at the pilot station. Asymmetrical ice shedding of the forward rotor system showed considerable increases in the vibration levels at the 1/rev and 6/rev frequencies on all axes (measured in the cockpit on the pilot's seat pad). The increased vibration levels were in all axes; however, the most pronounced increase was laterally.

g. Performance - No safety-of-flight limitations were encountered while operating in light-to-heavy icing conditions at static temperatures higher than -6.5°C and in light icing conditions greater than -8.5°C. Level flight performance was degraded as ice accumulated; therefore, a degradation in endurance and range can be expected due to an increase in engine torque required to maintain airspeed and altitude following ice accumulation. Qualitative pilot comments and

recorded control position data showed no apparent changes in the handling qualities of the helicopter due to ice accumulations.

h. Handling Qualities - Within the scope of this test, except for the degradation of handling qualities associated with increased vibration levels, the handling qualities of the CH-47C helicopter are not adversely affected by ice accumulation. Within the scope of these tests, the standard anti-ice systems functioned properly. Within the scope of these tests, the CH-47C aircraft equipped with unprotected T55-L-11A engines does not possess the capabilities to safely operate in an icing environment.

3. USAAEFA Project No 78-18, Artificial Icing Test CH-47C Helicopter with Fiberglass Rotor Blade, 1978 Icing Season (Reference A-8, Appendix A).

a. In 1978, USAAEFA, in conjunction with Boeing Vertol, conducted an evaluation of the CH-47C helicopter with fiberglass rotor blades (FRB) and a prototype deice system. Both natural and artificial icing conditions were evaluated. Testing was conducted in two phases: (1) protected, where the blade deice system was allowed to operate automatically and (2) unprotected, where the blade deice system was held in a standby status. The fiberglass rotor blade system was evaluated at conditions varying from 0.1 to 0.8 gm/m$^3$ LWC and temperatures varying from -4°C to -16°C. Test conditions are listed in Appendix B-2. The purpose of these tests was to determine:

(1) The effectiveness of the FRB deicing system and to provide the contractor with data for system optimization.

(2) The effectiveness of the unprotected FRB to operate in a light intensity artificial and natural icing environment. This condition would be limited to the effectiveness of the HISS to provide a suitable artificial icing environment.

b. The aircraft was a standard CH-47C helicopter, S/N 74-22287, with the following modifications:

(1) Installation of the fiberglass blades.

(2) Installation of T55-L-712 engines.

(3) Modified cockpit self-tuning vibration absorber.

(4) Aft fixed pylon with tuned absorber removed.

(5) Modified forward transmission cover actuator mount lugs.

(6) Modified swiveling actuator lower mount bearing and attachment hardware.

(7) Rotor hub assembly lightning protection.

(8) Emergency power system and revised engine start switch.

(9) Modified Longitudinal Cyclic Speed Trim (LCST).

(10) FRB deice system (integral with FRB).

(11) Data instrumentation package.

c. Instrumentation and Cloud Measuring Equipment - The test instrumentation consisted of the standard aircraft instruments plus calibrated test instrumentation. Data was recorded on magnetic tape and by hand. Special ice detection equipment consisting of three Rosemount 871 FA 121 ice detectors were installed on the test aircraft. A detailed listing of the test instrumentation is contained in Appendix C-3.

d. Ice Protection System - The CH-47C, with protected fiberglass rotor blades and integral blade deicing protection, was evaluated during seven tests in artificial icing conditions ranging from 0.25 to 0.75 gm/m$^3$ LWC, and a static temperature of -5°C to -16°C. The prototype rotor blade deice system operated satisfactorily, but required adjustment of the heat cycle on time following flights 1 and 3. After system on-time adjustments were completed, the system operated satisfactorily and provided excellent rotor blade ice protection. The CH-47C, with unprotected FRB, was evaluated in 12 flights in a combination of natural and simulated icing conditions. These conditions varied from an LWC of 0.10 to 0.75 mg/m$^3$ and a static temperature of -4°C to -15°C. No blade deicing was utilized during this phase (unprotected) of the test program; however, the deice system integral with the FRB was maintained in a standby mode in the event it was required. Operation of the CH-47C in icing conditions with unheated fiberglass rotor blades appears feasible.

e. Ice Accretion and Shedding Characteristics - With the deice system operating properly (after flight 3) in the automatic mode, the accreted ice was shed symmetrically from the protected FRB. Analysis of in-flight highspeed photographs on the unprotected FRB taken during artificial ice conditions showed low ice accretion characteristics and slight asymmetrical shed tendencies for the unprotected rotor blades. Ice would accrete from 2/3 to full span, then shed symmetrically at either blade station 85 or approximately 50 percent span. For all flights, only minimal cockpit indication of asymmetrical shed was observed. Within the limited scope of this test program, the unprotected fiberglass rotor blades show low ice accretion and minimal asymmetric shed characteristics.

f. Vibration - Vibration levels on the protected FRB remained essentially constant while in the icing cloud, and except for one 45-second period of mild 1/rev lateral oscillations indicating a mild asymmetric ice shed, no cockpit indication of asymmetric blade shed was observed. Indication of vibration was not found in the strip-out data. With the exception of one minute of mild 1/rev lateral oscillations occurring during flight 12, there were no observable cockpit indications of accreted rotor blade ice or asymmetric shed characteristics on the protected FRB. This vibration could not be verified in the data. Vibration levels remained constant at a given airspeed regardless of time in the icing conditions.

g. Performance - No degradation of performance was noted in either the protected or unprotected configuration when using the fiberglass rotor blades in an icing environment. Engine power (torque) did, however, steadily decrease throughout all flights as a result of fuel burn-off.

h. Handling Qualities - Within the scope of this test program, the prototype rotor blade deice system provided excellent rotor blade ·otection from icing. Also, operation of the CH-47C in icing conditions with unheated (unprotected) fiberglass rotor blades appears feasible following correction of the two deficiencies. Further, the windshield defog system is an excellent backup for the electrical windshield anti-ice system.

4. USAAEFA Project No. 79-07, YCH-47D Natrual and Simulated Icing (Reference A-9, Appendix A).

a. In 1980, USAAEFA was tasked to continue the earlier icing work on the CH-47C (Project No. 78-18). In the current test program, the YCH-47D with fiberglass rotor blades and an integral test deicing system was used as the icing test vehicle. Testing was again conducted in two phases: (1) protected (the deice system operated automatically) in a simulated icing environment, and (2) unprotected (the deicing system in a standby status), both in an artificial and natural icing environment. The YCH-47D was evaluated in conditions varying from 0.1 to 1.5 gm/m$^3$ LWC and temperatures vaying from -2°C to -20°C. The test conditions are listed in Appendix B-3. The purpose of these tests was to determine:

(1) The feasibility of establishing a flight envelope allowing the YCH-47D to operate continuously in light icing conditions and for 30 minutes in moderate intensity icing conditions without heated blade deice protection.

(2) The feasibility of establishing a flight envelope for the YCH-47D with heated blades to operate in icing conditions beyond the capability of the unheated blades.

(3) The effectiveness of the ice detection and ice accretion rate systems to provide adequate cockpit indications for safe operation under icing conditions.

(4) The effectiveness of the modifications applied to correct the problem areas encountered during prior tests.

The test aircraft, YCH-47D, S/N 76-5008, was equipped with production fiberglass rotor blades modified to incorporate heater blankets, an auxiliary 40

KVA generator mounted on the aft transmission, a test blade deice control system and an instrumentation package. Equipment modifications incorporated as a result of previous testing were: droop stop covers, conical screens around the fuel vents, and cabin heater drain tube redesign.

b. Instrumentation and Cloud Measuring Equipment - In addition to, or instead of, the standard aircraft instrumentation, calibrated test instrumentation was installed aboard the test aircraft. Data were recorded by hand from the cockpit instruments and on PCM encoded magnetic tape. Special ice measuring equipment was also installed on the test aircraft. This equipment consisted of:

(1) Two Rosemount Model 871FA nonaspirated ice detectors.

(2) One Leigh Ice Detector Unit (Mark XII (IDU-3).

(3) Two visual ice detectors.

(4) Still camera activated from the instrumented rotor blip through an intervelometer.

(5) Two fiber optic television cameras installed on the number two engine inlet.

A detailed description of the instrumentation package is contained in Appendix C-4.

c. Ice Protection System - No special ice protection systems were installed on the test aircraft other than the heated test fiberglass rotor blades.

d. Ice Accretion and Shedding Characteristics - Ice accreted on the full span of each protected rotor blade before the deice system was activated. No asymmetric ice sheds or unusual vibrations were noted during these tests. The deice system on time was similar to that used for the 1979 icing tests. The system, when activated to remove large ice buildups, operated satisfactorily. Within the scope of these tests (temperature range -12 to -20°C and LWC of 0.35 to 0.54 gm/m$^3$) the prototype rotor blade deice system provided excellent results. During the unprotected rotor blades (unheated) icing tests, the natural icing conditions varied greatly in terms of LWC during any given flight. The non-homogeneous nature of the cloud resulted in LWCs varying from a maximum of 0.69 to a minimum of 0.1 gm/m$^3$ on a single flight. The coldest temperature encountered in the natural icing environment was -13°C with an average LWC of 0.2 gm/m$^3$. With the exception of a very mild 1/rev lateral oscillation which occurred momentarily during flight 6, there were no observable cockpit indications of accreted rotor blade ice or asymmetric shed characteristics. Ice accretion along the full span of the blade was documented on still and high speed motion photography. An analysis of in-flight high speed photographs taken after exiting the cloud indicated that the pieces of ice shed from the forward head advancing blades were projected forward along the flight path of the aircraft. The ice would then impact the bottom of the succeeding advancing blade. Pieces of ice also passed through the retreating blades of the aft rotor system. The projected path indicated impact would occur on the underside of both forward and aft rotor blades. Small dents and voids were detected during post-flight inspection on the underside of the forward and aft rotor blades. The majority of these dents were incurred during the natural icing flights

conducted at maximum level flight airspeed $V_H$. These anomalies were considered minor and it was concluded that under the conditions tested, the YCH-47D with unheated blades can operate continuously at temperatures down to -5°C with up to 0.5 gm/m$^3$ LWC without incurring significant blade damage or asymmetric shedding. Four flights were conducted behind the HISS to expand the LWC and temperature range with unheated blades. In two of the tests (tests 5 and 8), the forward rotor system was immersed in the cloud and 18 minutes into the test a 2-1/2 foot piece of ice shed from a forward rotor blade at station 180. A lateral 1/rev acceleration of 0.4g resulted from the shed and the test aircraft exited the cloud. The blade track was measured five inches out of the tip path plane.

The vibration level could not be reduced by either varying the rotor speed or changing the collective pitch setting and varying the airspeed. The blade deice system was then activated and at the end of approximately 30 seconds the vibration level was eliminated. In another test (test 9) at -10°C and LWC of 1.2 gm/m$^3$ with the forward head immersed in the artificial cloud, intermittent asymmetric sheds and vibrations occurred, but dissipated rapidly. High speed photography showed large pieces of ice shedding intermittently from the forward rotor system traveling past the aft pylon. One piece of ice, 2-1/2 inches in diameter, passed through the aft rotor system. The risk of blade damage and asymmetric shedding with unheated rotor blades increases significantly at colder temperatures and higher LWC. Rotor blade damage incurred from ice sheds at -10°C and a flow calibrated LWC of 1.2 gm/m$^3$.

e. Vibration - Aircraft vibration, exclusive of ice sheds noted previously, was evaluated qualitatively during cold weather operations. Vibration levels became excessive as airspeeds approached 145 knots indicated airspeed (KIAS) at 225 rpm. Above this airspeed, vibration levels increased rapidly with unacceptable levels reached prior to $V_H$. Vibration levels were predominantly at 6/rev and would effectively restrict the helicopter to 145 KIAS for continuous operation.

f. Performance - No performance anomalies other than those previously noted were reported during this test program.

g. Handling Qualities - No handling qualities anomalies were noted during the test.

h. Conclusions - As a result of this test program, the following conclusions were reached:

(1) The CH-47D, with unheated rotor blades, can operate continuously at temperatures down to -5°C with up to 0.5 gm/m$^3$ LWC without incurring significant blade damage or asymmetric ice shedding.

(2) The risk of blade damage and asymmetric shedding with unheated blades increases significantly at colder temperatures and higher LWC.

(3) A reliable cockpit indication of the icing environment is necessary.

(4) The aft droop stop covers, fuel vent screens, and modified cabin heater drain performed satisfactorily under the conditions tested and corrected the previously reported deficiencies.

(5) Flights in continuous light icing conditions and snow down to -15°C with engine anti-ice OFF were accomplished without incurring engine damage.

(6) The ice detectors tested provided an approximate accretion rate; however, due to the high crew workload necessary to use the devices, it is believed they would be operationally impractical.

5. USAAEFA Project No. 80-16, Limited Artificial Icing Tests of the OV-1D, (Reference A-10, Appendix A).

a. Operational experience in Europe indicated that during flight in icing conditions, ice accretes on the OV-1D engine nose cowling assembly. It was suspected that this accreted ice might break off the engine nose cowling and be ingested into the engine. As a result of these concerns, USAAEFA was tasked to conduct a limited artificial icing evaluation on the OV-1D aircraft. The purpose of these tests was to determine:

(1) The ice accretion characteristics of the engine nose cowling assembly propeller, and propeller spinner.

(2) If the accreted ice is being ingested into the engine.

(3) The ice accretion characteristics of the louvered, scarfed shroud suppressor (LSSS).

(4) The effect of ice accumulation on the operation of the infrared countermeasures (IRCM) pod AN/ALQ-147A(V)1.

b. The test aircraft was a standard OV-1D S/N 68-15932 configured with the LSSS scoop, AN/ALQ-147A(V)1 on wing station 6 and Sergeant Fletcher fuel tanks on stations 3 and 4. The aircraft was flown for a total of 11 test flights in artificial icing conditions and 1 flight in natural icing conditions. Flights in the artificial icing environment were conducted at ambient temperatures and liquid water content which approximate natural icing conditions of moderate intensity. Test conditions are listed in Appendix B-4. Prior to entering the icing cloud, the test aircraft's pitot heat, propeller, and cowling deice systems, and the engine bleed-air-operated windshield defog system were turned ON. Anti-ice and deice systems were operated continuously while in the icing environment, with the exception of the wing and tail deice boots and windshield anti-ice which were activated as required. The aircraft was configured with the landing gear, flaps, and speed brakes retracted, and was flown in the cloud for 30 minutes at each predetermined LWC and OAT.

c. Instrumentation and Cloud Measuring Equipment - Standard onboard aircraft instrumentation and photographic documentation from the test aircraft, HISS, and chase aircraft were used to document the test results in the artificial ice environment and the test aircraft in the natural ice environment. The visual ice accretion probe was used to assist in determining ice buildup while in the cloud. The Rosemount ice detector, while used, was unreliable. Operational status of the AN/ALQ-147(V)1 was monitored by the system cockpit status indicator during flight.

d. Ice Accretion and Shedding Characteristics - Ice buildup was observed on heated surfaces inside the engine nose cowling assembly air inlet, on the propeller spinner, and on the propeller heaters during all test conditions. Ice

accretions were also observed during flight on the heated portions of the three nose cowling struts and inner walls of the engine cowling inlet. The ice accretions were evident at all temperatures tested with the largest accretions at colder ambient temperatures or higher LWCs. Four first stage compressor turbine blades were damaged during the 30-minute icing encounter at 20°C and 0.5 gm/m³ LWC. One damaged second stage compressor turbine blade was found during engine teardown at the completion of the test. Three inlet guide vanes behind the 4 o'clock cowling strut were bent and one first stage compressor turbine blade was damaged beyond repair. The end of the propeller spinner accreted a one-to-two-inch thick donut shaped ice formation which extended aft along the spinner. Ice accumulated on the propeller blade heaters on all icing flights. Asymmetric propeller ice sheds induced high frequency airframe vibrations which often lasted three to five minutes. Throughout the tests, the engine nose cowling assembly, propeller, and propeller spinner ice protection systems did not prevent ice accretions. The airframe and external fuel tank were damaged, high frequency airframe vibrations occurred from propeller ice shedding, and engine inlet guide vanes and compressor blades were damaged due to ice ingestion. Although the windshield defog and alcohol anti-ice systems were turned on prior to entering the icing conditions, the forward field-of-view through the pilot's and copilot's windshield was distorted and severely reduced. On two separate icing flights at -10°C and 0.75 gm/m³ LWC, the AN/ALQ-147A(V)1 failed to operate at an airspeed of 135-150 KIAS. Ice had accumulated on the air door jack screw inside the air inlet. This ice buildup apparently restricted the air door movement thus preventing proper air modulation for combustion. The LSSS inlet scoop accreted an insignificant amount, 1/8 inch by 12 inches, of ice into the thread of the inlet. This amount would not degrade the scoops effectiveness.

e. Handling Qualities - No handling qualities anomalies were observed during the test.

f. Conclusions - Under the conditions tested, the following characteristics were observed:

(1) Ice accretion characteristics of the LSSS inlet scoop are satisfactory.

(2) Ice accretion characteristics of the engine nose cowling, propeller, and propeller spinner can result in engine damage.

(3) Failure of the windshield ice protection system to clear the windshield sufficiently to provide adequate forward field-of-view after encountering icing conditions.

(4) Lack of an adequate engine nose cowling, propeller, and propeller spinner ice protection system status indicator.

(5) Failure of the AN/ALQ-147A(V)1 to operate due to ice accumulation in the inlet.

6. USAAEFA Project No. 81-21, Limited Artificial and Natural Icing Test of the OV-1D (Re-Evaluation) (Reference A-11, Appendix A).

a. In 1982, USAAEFA again conducted icing evaluation on the OV-1D. This program was a result of improvements made by Grumman Aircraft Corporation in an

effort to correct the deficiencies and shortcomings identified during the 1980 program (Project No. 80-16). The program, as initially planned, was a two-phase program. The first phase was with the existing OV-1D 6.5 KVA generator uprated to 7.5 KVA, insulation added to the cowling interior, and revised heating element cycle times. Phase II incorporated a 9.0 KVA generator and additional changes to the heater element cycle times. Both of these phases were to be conducted in an artificial icing environment. A third phase was subsequently added which included further modifications to the Phase II program and was conducted in a natural icing environment. The purpose of the test program was to determine the ice accretion characteristics of the modified OV-1D engine cowl ring and determine if accreted ice is subject to being ingested into the engine. Also to be verified was the adequacy of the modified engine ice protection in natural icing conditions. The test aircraft was a standard OV-1D, S/N 68-15932, configured with the LSSS and two 150 gallon Sergeant Fletcher Fuel Tanks on wing stations 3 and 4. The aircraft also incorporated the following modifications by Grumman:

(1) <u>Phase I Tests</u>

(a) Uprating the existing 6.5 KVA deice generator to 7.5 KVA.

(b) Foam insulating material was added to the fixed and removable cowling halves (except the cowling struts).

(c) OAT sensor added to alert the pilot to deactivate the deice system when temperatures were above freezing.

(2) <u>Phase II Tests</u>

(a) Installation of two redesigned/reworked deice generators with a rating of 9.0 KVA.

(b) Modification of the deice timing cycle to utilize the added electrical power.

(3) <u>Phase III Tests</u>

(a) Further modification of the deice timing cycle on time.

(b) Insulation added to the cowling struts.

(c) Propeller blade butt boots disconnected from the deicing timing circuit.

Artificial icing tests were conducted by immersing the right engine in the artificial icing cloud. Natural icing conditions were located by the U-21 chase aircraft, then the OV-1D flew in these conditions. The test conditions are listed in Appendix B-5.

b. <u>Instrumentation and Cloud Measuring Equipment</u> - For cloud measurements in both the natural and artificial environments, data were recorded by a specially instrumented U-21A aircraft. This instrument package consists of:

(1) Particle Measuring System (PMS).

(2) Forward Scattering Spectrometer Probe (FSSP).

(3) A PMS optical array cloud droplet spectrometer probe.

(4) Rosemount OAT sensor and display.

(5) Cambridge model 137 chilled mirror dew point hygrometer and display.

(6) Leigh MK 10 ice detector unit with digital display.

(7) Small Intelligence Icing Data System (SIIDS).

Also used to document the results of these tests were comments by the observer in the right seat of the OV-1D and photographic documentation.

c. Ice Protection Systems - The ice protection systems and the modification to these systems were explained previously under the aircraft configuration.

d. Ice Accretion and Shedding Characteristics - During Phase I ice buildups were observed on heated surfaces inside the engine cowling on both of the flights. Ice accretions were evident at both temperatures tested (-4°C and -20°C) with largest accretions at -20°C. The ice accretion characteristics of the Phase I engine nose cowling may result in engine damage; however, this configuration was an improvement from the results seen in the previous test program (Project No. 80-16). During Phase II ice was not observed on the heated portion of the cowling under the tested conditions (-5°C to -20°C and LWC of .56 to 1.04 gm/m$^3$) however, ice did accrete just aft of the heated portion. Liquid water was observed running back on the outside of the cowling and freezing on the unheated surfaces at all temperatures. Ice accretion characteristics of the external and internal engine nose cowl assembly is considerably improved over the standard system; however, ice still forms on the cowling joints and extends around the leading edge of the cowling where it could break off and cause engine damage. During Phase III a small piece of ice accreted on the No. 1 engine inboard cowling half joint leading edge at each of the conditions tested (5 tests with OAT ranging from -7.0°C to -13°C and LWC between 0.18 and 0.50 gm/m$^3$). This ice would periodically break off and was probably ingested into the engine although no engine damage was observed during post flight inspections. Both engine cowling struts and inlet interior appeared to be free of ice as viewed from the chase aircraft. The Phase III configuration of the No. 2 engine nose cowling assembly exhibited the best ice accretion characteristics of all the configurations tested; however, ice still formed on the engine cowling joints and extended around the leading edge of the cowling where it could break off and cause engine damage. During Phase II at all test conditions, ice formed on the forward edge of the spinner. This ice was one to two inches thick and formed in the shape of a donut. This ice departed the spinner when the OAT was above freezing. It is possible that this ice might be ingested through the engine inlet; however, this was never observed. Throughout the Phase III testing, both propellers remained relatively free of ice except for the tip of the spinners which accreted a donut-shaped ice formation. A possibility exists that the propeller spinner ice donut may be ingested through the engine inlet; however, this condition was not observed on any of the flights. During Phase II Ice formed on the propeller, butt boots, and blades at all conditions

tested. The propeller blades randomly shed ice which caused moderate air frame vibrations and damaged the skin of the fuselage and drop tanks. During Phase III asymmetric propeller ice sheds resulting in airframe vibrations occurred at all the conditions tested. The propeller ice sheds were random and the frequency of the shed was a function of the icing severity. The engine was visually inspected after each flight. There was no evidence of engine damage found during the artificial icing tests. Propeller ice sheds occurred in all of the icing conditions tested. Ice departing the blades frequently hit the fuselage or fuel drop tanks. Dents as large as 1/4 inch deep and three inches in diameter were observed on the drop tank. The windshield defog system was used during Phase II to determine its effectiveness in deicing the windshield. It was not effective. The windshield alcohol system was useless at -20°C and caused ice slush which was smeared over the windshield at warmer temperatures. During Phase III The adequacy of the windshield alcohol anti-icing system was a function of the type of icing environment. The amount of reduced field-of-view appeared to be a function of droplet size which cannot be determined by the operational pilot. The windshield ice protection system would not clear the windshield sufficiently to provide an adequate forward field-of-view after encountering icing conditions.

e. <u>Performance</u> - Performance degradations occurred at each icing condition encountered with the most significant loss observed at 0.28 gm/m$^3$ LWC and -7.5°C with MVDs ranging from 33 to 240 microns in cumuloform clouds. Ice accretion on the propeller appears to be a significant contributing factor to overall decrease in aircraft performance when the icing conditions are initially entered. Large supercooled water droplets create high drag ice formations when contacting the airfoil surface and rapidly degrade aircraft performance. The icing condition was entered at 170 KIAS at a cruise power setting. After five minutes, the airspeed had decreased 20 knots. The airspeed further decreased to 130 KIAS with a cruise power setting, after having been in the cloud for 20 minutes. The wing deice boots were activated after 1-1/2 inches of ice had accreted on the wings but were only partially effective in removing the ice from the wing and tail surfaces, restoring only five knots of airspeed. The prestall airspeed observed in these tests indicates that the actual stall speed with ice on the wings may be considerably higher than that shown in the Opertor's Manual. As the airspeed decreased from the loss of propeller and wing performance, the angle-of-attack was increased in order to maintain altitude. This exposed more of the underside of the wing to the inflow of water droplets resulting in high drag ice formations under the wing aft of the deice boot. This additional drag further decreased the airspeed and required a still higher angle-of-attack to maintain altitude. These icing conditions (0.28 gm/m$^3$ LWC and OAT of -7.5°C with MVDs of from 33 to 240 microns) were more severe than the airframe ice protection is capable of handling.

f. <u>Handling Qualities</u> - No abnormal handling qualities were observed during the test.

g. <u>Conclusion</u> - Based on the limited artificial and natural icing evaluation, under the conditions tested, it was concluded that:

(1) The Phase I and II modified engine nose cowling resulted in improved ice accretion characteristics, but ice still forms which may cause engine damage.

(2) The No. 2 engine cowling assembly Phase III changes exhibited the best ice accretion characteristics of all the configurations tested.

(3) Based on the fact that a performance increase was observed after a propeller shed, it is believed that a propeller system with an anti-ice capability would result in significantly less performance degradations when operating in an icing environment.

7. USAAEFA Project No. 76-09-1, Artificial Tests Utility Tactical Transport Aircraft System (UTTAS) Sikorsky YUH-60A Helicopter (Reference A-12, Appendix A.)

a. The U.S. Army requires an improved operational capability in its utility transport aircraft to satisfy the demand for increased performance and survivability in the mid-intensity combat environment. The utility tactical transport aircraft system (UTTAS) was developed in response to this requirement and will replace the current utility helicopter in the Army inventory. On 30 August 1972, the U.S. Army Aviation Systems Command (AVSCOM) awarded a contract to the Sikorsky Aircraft Division of United Technologies Corporation to produce three prototype aircraft and one ground test vehicle. USAAEFA completed an Army Preliminary Evaluation of the Sikorsky YUH-60 in March 1976. A Government Competitive Test (GCT) was completed in September 1976. The UTTAS was designed to operate under climatic conditions up to and including moderate icing. USAAEFA was tasked by AVSCOM to conduct artificial icing tests of the YUH-60. The overall test objectives of the YUH-60 artificial icing tests were as follows:

(1) To provide data to be used for evaluating the ability of the helicopter to efficiently operate in a moderate icing environment.

(2) To detect and allow for early correction of any aircraft deficiencies or shortcomings.

(3) Evaluate the effectiveness of the windshield, pitot static, engine air induction, and engine anti-ice systems.

(4) Determine the need for additional anti-ice/deice systems.

(5) Heated blade phase: determine the potential effectiveness of the contractor provided prototype anti-ice/deice system.

b. The test aircraft, YUH-60, S/N 73-21651, was configured with a prototype deice system and an anti-ice system which used a variety of methods to provide ice protection. Test conditions are shown in Appendix B-6. In-flight artificial icing, utilizing the HISS, was conducted in the vicinity of Fort Wainwright, Alaska, from 12 October through 3 November 1976. A total of 10 icing flights were conducted, totaling 9.7 hours, of which 3.9 hours were in the artificial icing environment. Density altitude varied from -1,060 to 8,960 feet. Icing was accomplished at ambient temperatures from -5.5 to -16.0°C and at liquid water content (LWC) levels of 0.25 gram per cubic meter (gm/m$^3$) and 0.5 gm/m$^3$. A summary of icing test conditions is presented in Appendix A-6. The test airspeed in the icing environment was 90 knots true airspeed (KTAS) and main rotor speed was 258 revolutions per minute (rpm).

c. Instrumentation and Cloud Measuring Equipment -

(1) In addition to, or instead of, standard aircraft instruments, sensitive calibrated instrumentation was installed aboard the test aircraft and maintained by the contractor. Data were recorded from the cockpit instrumentation and the specially installed instrumentation system. Data were recorded on flight data cards and magnetic tape (PCM and FM). Selected parameters were observed real-time via air-to-ground telemetry (TM). A detailed instrumentation and special equipment list is presented in Appendix C-5.

(2) Cloud measuring equipment included an ice detector (Normalair-Garret) and a visual ice accretion probe installed on the test aircraft to correlate the icing severity levels experienced by the test aircraft with the LWC established by the CH-47C spray aircraft and to document ice accumulation. Two additional ice detectors (Rosemount Model 871FA) were installed as part of the aircraft deice system (para. 15).

(3) Two Teledyne 16mm camera systems, Model DBM 44, were installed on the test aircraft to photograph the main and tail rotor blades inflight. The camera film magazine held 200 feet of film and camera shutter speeds of up to 400 frames per second (fps) were available. Another 16mm high-speed hand-held motion picture camera was located on board the chase aircraft and was used to document the test aircraft both in the spray cloud and after exit from the cloud. Additionally, 35mm color slide and black and white still cameras were used for documentation both in the air and on the ground following each icing flight. Film obtained from the camera mounted on the test aircraft did not have sufficient sharpness of clarity to permit an analysis of ice accretion and shedding on the main or tail rotor blades. This was caused by the low ambient light conditions and the unsatisfactory view angles from the locations where the camera was mounted.

d. Ice Protection Systems -

(1) The deice system installed in the YUH-60 helicopter was a prototype electrothermal system made up of the following eight subsystems: cockpit control and associated lights; ice detector (two each); outside air temperature (OAT) sensor (three each); controller with two complete sets of logic; distributor; slip ring assemblies (one each for the main and tail rotors); electrothermal heater mats; and deicing engineer control panel. Electrical power from and No. 2 AC generator (115 VAC, 30 kVA, 400 Hz) was used to operate the system while the DC bus was used to control the system. Total electrical power required for this prototype system was estimated to be 25 kVA. A prerequisite for system operation in any mode was 90 percent rotor speed or greater.

(2) Two Rosemount Model 871FA ice detectors were provided with the prototype deice system. One detector was attached to the outboard side of each engine cowling between the engine compartment cooling air scoops. The detector installed on the left side of the aircraft was aspirated by engine bleed air and provided the ICE-DETECTED signal used to automatically turn the system on and off when the AUTO mode was selected. The unaspirated detector installed on the right side of the aircraft provided the ICE-DETECTED signal to the Rosemount 512P icing rate meter mounted on the deicing engineer control panel. The icing rate meter readings were unreadable and constantly fluctuated from light to moderate and occasionally gave a trace indication while in the icing cloud. By

comparison, the rate signal from the aspirated ice detection gave reasonable comparison data with the icing severities established by the spray aircraft.

(3) Three separate malfunctions of the Rosemount ice detectors were noted during ice tests. The malfunctions were physical damage to the ice detector probe mounted on the No. 2 engine nacelle; freeze up of the ice detector probe mounted on the No. 1 engine nacelle; also, erroneous ICE-DETECTED indications were presented when the fairing heater for the tail cone-mounted tail rotor camera was turned on. Since the heated camera fairing was part of the special instrumentation, the EMI associated with its operation is not considered a problem; however, the presence of EMI does indicate that EMI shielding will be needed when electrical components that use large quantities of electrical power are installed. Data analysis after flight 13 revealed that the Rosemount ice detector probe mounted on the No. 2 engine nacelle had malfunctioned throughout the flight. Inspection of the icing probe by a Rosemount technical representative revealed that the probe had been bent. Although not confirmed, the probe could have inadvertently been bent during maintenance, since the probe is about knee heigh as one steps from the treadway in front of the engine intake to and from the work platform. The damaged ice detector was replaced.

(4) After flight 16, visual inspection of the aspirated Rosemount ice detector probe mounted on the No. 1 engine nacelle revealed that the probe had frozen over. A continuity check was made of the heater element circuit, and a broken wire was discovered. The broken wire was repaired and no additional probe freeze-up occurred.

(5) Three identical Rosemount 159U outside air temperature (OAT) sensors were provided with the deice system. All three were mounted on the nose section between the center windshield and the nose door, with a shield installed in front of the sensors to eliminate kinetic heating effects. One sensor was used to provide a temperature signal to the controller that would limit heater mat ON time to 1 second when OAT was 2°C or greater, and the mode select switch was in either the AUTO or MANUAL position. This was the rotor blade over-temperature protection feature of the deice system. This feature provides redundant protection when the mode select switch is left in the AUTO position since ice should already be shut down. The two remaining sensors provide temperature inputs to the controller to regulate system ON times in the MANUAL or AUTO mode, respectively, since each mode has an independent set of control and logic circuitry.

(6) The electrothermal heater mats were embedded in the leading edge of each main and tail rotor blade. The mats consist of a series of strain relieved wires running spanwise, woven uniformly (24 wires per inch) into a stabilizing fabric carrier. The main rotor blade mat was divided into four electrically independent heater zones, while each tail rotor blade had only one heater zone. Heater mat coverage for the main rotor blade was 35 to 95 percent spanwise; and 8 percent upper, 12 percent lower chordwise. Heater mat coverage for the tail rotor blades was 48 to 98 percent spanwise, and 16 percent both sides chordwise. Power density for the main and tail rotor blades was 25 to 10 watts per square inch, respectively.

(7) Deice system ON and OFF times were manually set inflight at the deicing engineer control panel. Eight temperature transducers embedded in one

main rotor blade and two temperature transducers embedded in one tail rotor blade provided a means of measuring blade surface temperature during system operation. The temperatures were then displayed by means of 10 visual indicators mounted on the deicing engineer control panel. Additional indicators of system operation included lights that illuminated when electrical power was being applied to either the main or tail rotor heater mats and a Rosemount 512P icing rate indicator. One switch installed on the control panel simulated ice detected and provided the controller with false ICE-DETECTED signal. Another switch provided an ice detector test feature and also turned the Rosemount detector test on and off. The system was adjusted through two banks of control potentiometers, also located on the control panel, that allowed for independently setting main and tail rotor system On and OFF times. Since the controller had two identical sets of circuitry, one bank was for the AUTO mode and the other for the MANUAL mode. By monitoring the blade surface temperature, the deice engineer could select any desired setting, as follows:

| | |
|---|---|
| Main rotor zone heating time | 1 to 24 seconds |
| Tail rotor zone heating time | 1 to 40 seconds |
| Main rotor OFF time | 1 to 4 minutes |
| Tail rotor off time | 0.3 to 2 minutes |

e. Ice Accretion and Shedding Characteristics -

(1) The main rotor deiced blades all showed the same ice accretion and shedding characteristics. At the end of the flights of longest immersion for each test condition, the protected areas (35 to 95 percent spanwise; 8 and 12 percent chordwise top and bottom, respectively) were clear of ice and there was no evidence of runback on either side of the blade. There was, however, a large ice buildup on the inboard unprotected portion of the blade, and a significant buildup aft of the protected area on the bottom side of the blade out to approximately 60 percent span. Following a 34 minute immersion at -10°C and LWC of 0.5 gm/m$^3$ (flight 17), ice thickness was 1 inch on the leading edge of 15 percent span. During the flight, ice accreted as a solid mass on the unprotected leading edge and wrapped around the leading edge from approximately 10 percent chord, top side, to approximately 20 percent chord on the bottom side. Aft of the solid wrap-around ice in the unprotected area, there was "stalk" ice on both top and bottom of the blade. (Stalk ice is defined as ice that forms slender irregular shaped rods of ice, generally into the direction of the local airflow.) The amount observed on the top side of the blade was sparsely located; however, the stalk ice formation extended to the trailing edge on the bottom side of the blade out to approximately 60 percent span. Discontinuities on the bottom side of the blade, such as the boron strip near the trailing edge, showed a pronounced affinity for ice accretion. This accretion pattern was typical for all three of the long immersion flights.

(2) With the deice system operating, the protected portion of the blade controlled the ice accretion and produced a symmetrical shedding. Visual observation and high-speed motion pictures revealed that the shedding occurred at random blade azimuth positions, making it impossible to predict ice trajectory. At times the shed ice was struck by the following blade, and shattered into smaller particles. Visual inspection of the main rotor blades after each flight

revealed no damage to the blades other than an occasional paint chip. The crew heard ice striking the airframe and observed ice striking the windshield; however, visual inspection revealed no damage to either. The remainder of the shed ice seemed to drop away with little or no horizontal velocity imparted due to blade rotation. The engines were borescoped after each icing test flight. The results of the borescope observations revealed no FOD to the compressors, even though ice was observed and photographed entering the engine inlets. Within the scope of this test, the ice shedding characteristics of the protected portion of the main rotor blades with the deice system operating were satisfactory.

(3) The stalk ice that accreted on the bottom side of the main rotor blade showed no tendency to shed, either naturally or as a result of a rotor speed sweep. The solid wrap-around ice attached to the unprotected inboard portion of the leading edge did shed both naturally as a result of rotor speed sweeps. Natural shedding was characterized by a momentary increase in lateral vibrations at the pilot seat, coupled with a reduction in the engine power required to remain in the icing environment. During a 39 minute immersion at -11°C and 0.5 gm/m$^3$ LWC (flight 17), one inch of ice accreted on the leading edge out to 14 percent span, and 1/4 inch of ice accreted from 14 to 17 percent span, indicating that a natural shed occurred. A rotor speed sweep was also accomplished during this flight after postcloud trim data were recorded by beeping the rotor to 105 percent and then immediately beeping to 98 percent. Lateral vibrations similar to those present during the ice cloud immersion were felt during the rotor speed sweep. Trim data recorded afterwards revealed a significant reduction in power required. The postcloud average torque reading was 57 percent, which dropped to 45 percent following the rotor speed sweep. A rotor speed sweep was also accomplished after postcloud trim data were recorded on a 44-minute flight at -16°C and 0.25 gm/m$^3$ LWC (flight 19) in which the induced shed was not symmetrical and a very uncomfortable 0.15g one per-rotor-revolution (1/rev) lateral vibration was recorded from the Chadwick-Helimuth vibration meter. Several additional rotor sweeps failed to eliminate the asymmetric condition, and therefore, a rotor speed sweep [illegible] a satisfactory means of shedding ice from the inboard portion of the blad[illegible] it was not always successful. The ice protection of the main rotor bla[illegible] inadequate.

(4) Visual inspection of the main rotor hub area after each ic[illegible] flight revealed symmetrical ice accretion on similar components with no [illegible]e of any shedding. The amount of ice accreted depended on location, with t[illegible] components on the top accreting more ice than those on the bottom. During typical flight the thickness of the ice on the bifilar weights was 1/2 inch. Each weight had complete freedom of movement. There was no apparent changes in vibration levels attributed to ice accretion on the bifilar weights. The remainder of the moving components in the hub area, such as droop stops, pitch change rod ends, lag dampers, and elastometric bearings, are somewhat protected and showed no indication of accreting enough ice to impair movement.

(5) A bulbous ice accretion on the lower end of the pitch change link was typical for all icing flights. There was no evidence of interference between the ice and the airframe or that interference would occur with ice growth during longer flights. Loads in the pitch change links were recorded and no significant increase in loads as a function of ice accretion on the links or the rotor blades was noted.

(6) Visual inspection of the tail rotor after each icing flight revealed ice on all components of the tail rotor. Accretion patterns on each tail rotor blade were the same. The accretion patterns on each pitch change link were also the same. The remaining components of the tail rotor all accreted ice; however, like the blades and pitch change links, the ice thickness was always less then the ice accreted on the vertical fin. Some evidence of localized natural shedding was seen at about 30 percent span; however, it appeared to be a function of flexing in that area, and was never observed to have progressed beyond 40 percent span. Ice trajectory as a result of deice system operation or natural shed was not determined photographically; however, visual inspection of the airframe revealed no damage.

(7) Films taken from the chase aircraft indicate that the exhaust plume from the HISS is deflected downward in the area of the top half of the tail rotor disc. There could also be some heating of the tail rotor by the YUH-60 exhaust plumes. Attempts to determine if the exhaust plumes were heating the tail rotor were unsuccessful using the imbedded temperature sensors in the tail rotor. Films also showed that the top 40 percent of the tail rotor disc is not in the spray cloud when the main rotor is centered vertically in the spray cloud. Further tests should be accomplished with the tail rotor fully immersed in the spray cloud and with infrared countermeasure devices installed.

(8) Visual inspection of the stabilator after each icing flight revealed different accretion patterns for the right and left sides. The clear ice along the inboard leading edge on the left side suggests that the engine exhaust is influencing accretion patterns in that area. Ice accreted on the inboard end did not restrict stabilator movement. Evidence of a natural shedding was only observed on the right stabilator tip, and occurred outboard of the splice. Qualitatively, handling qualities were unaltered due to ice accretion on the stabilator.

(9) Generally, each flight revealed that ice would accrete on any unprotected portion of the airframe exposed to the free stream. Airframe surface and components which displayed significant accretion and/or shedding characteristics were the windshield frames, center windshield, windshield wiper, pilot doorframe, pitot-static support strut, and engine nacelle. The influence of the significant accretion and/or the FOD potential was judged a shortcoming for each of the above listed surfaces or components.

f. Vibration -

(1) Generally, the main rotor 1/rev and 4/rev vibration levels remained unchanged after flight in the icing environment. While in the cloud, the main rotor 1/rev and 4/rev vibrations increased slightly at the pilot seat and aircraft cg in all axes. These increases in vibration levels were normally associated with ice shedding from the main rotor during and after a deice system heating cycle or a natural shed. The increased vibrations were not uncomfortable to the crew. There were no significant changes in the main transmission or tail rotor gearbox vibration levels.

(2) A rotor speed sweep to 105 percent was conducted during a flight at -16°C and 0.25 $gm/m^3$ LWC just after a deice heating cycle (after approximately 30 minutes in the cloud) in an attempt to shed the ice remaining on the inboard section of the main rotor. Additional ice was shed from the main rotor;

however, it was not shed symmetrically. This asymmetrical shed of ice caused a significant increase in the main rotor 1/rev vibration level in all axes. The 1/rev vibration at the pilot seat in the lateral axis was predominant. It increased from 0.05g just before the rotor speed sweep to 0.12g. This level of vibration at the main rotor 1/rev frequency was very uncomfortable to the pilot and copilot. The 1/rev vibration on the vertical axis was predominant at the aircraft cg.

g. Performance

(1) A limited level flight evaluation of the YUH-60 helicopter was conducted at the test conditions shown in Table 1. The level flight performance data were obtained from pre- and postcloud test data. A summary of the individual test results is shown in Appendix B-6. The power required for level flight increased after flight in the icing environment at the same trim airspeed.

(2) The level flight performance tests without the deice system operating were limited to flights that determined deice system OFF times. Significant increases in power required for level flight were encountered after only a few minutes exposure to the icing environment. Insufficient data precluded precise assessment of the test helicopter's capability for continuous flight in icing conditions.

(3) The power required for level flight during the heated phase tests also showed a significant increase with the accumulation of ice on the aircraft. The additional power required ranged from 15 to 31 percent of the precloud trim point. On flight 8 in programmed o.25 $gm/m^3$ LWC and -5°C, the icing cloud was entered with a power available margin of 24 percent. After 7 minutes, continued flight in the cloud was not possible because of insufficient power. Repeated attempts to reenter and remain in the icing cloud was unsuccessful. During flight 17 (programmed 0.5 $gm/m^3$ LWC and -11°C), after the postcloud performance tests were completed, a rotor speed sweep to 105 percent was conducted in an attempt to shed the ice remaining on the inboard section of the main rotor. Shedding was observed during the rotor speed sweep and as a result, the power required for level flight decreased to approximately half of the total power required for level flight at the precloud trim point. This indicated that a large portion of the increase in level flight power required was due to the ice remaining on the leading edge of the unprotected inboard section of the main rotor blade. The ice protection of the main rotor blades was inadequate.

(4) Engine performance tests were conducted to quantify the power available losses due to engine and engine inlet anti-ice systems. Tests included flight with both systems OFF for baseline data with engine only anti-ice ON; and with both systems ON. Pitot head, windshield anti-ice systems, and cabin heat remained on during all these tests. Dual engine power available was reduced by 685 shaft horsepower (shp) due to the engine and engine inlet anti-ice systems operation. The engine anti-ice system contributed 69 percent of the total power available loss and the engine inlet anti-ice systems operation. The engine anti-ice system contributed the remaining 31 percent. The No. 1 and No. 2 engines contributed 360 to 325 shp, respectively, to the power available loss. This power available loss was based on turbine inlet temperature, which was the limiting engine parameter at the test condition flown. The loss of engine power available with anti-ice system operation was excessive.

(5) The pre- and postcloud data show that a decrease in autorotational descent performance occurred with ice accumulation on the main rotor blades. The test results with clean blades and blades with ice accumulated are difficult to compare because of the gross weight, density altitude, and collective control position changes and lack of sufficient baseline autorotational data with the heated rotor blades. After a 53 minute flight at -12°C and 0.25 gm/m$^3$ LWC (flight 14), the stabilized autorotational rotor speed was at the minimum power off continuous rotor speed limit of 95 percent with the collective control full down. The maximum continuous power off rotor speed allowed by the safety-of-flight release was 105 percent. On flights 17 and 19, the ship's system airspeed indicator fluctuated five knots while in the stabilized autorotation. This fluctuation was attributed to the turbulent airflow caused by the buildup of ice at the top of the windshields in front of the pitot-static probes. The autorotational descent performance, as a result of ice accumulation, was degraded.

g. Handling Qualities - Handling qualities appeared qualitatively to be unchanged due to ice accretion.

8. USAAEFA Project No. 78-05, Artificial and Natural Icing Tests, Production UH-60A Helicopter (Reference A-13, Appendix A).

a. Artificial icing tests were previously conducted in Alaska by USAAEFA using a prototype YUH-60 with a prototype main and tail rotor deice system and anti-ice provisions for the pilot and copilot windshields, pitot-static tubes and their support struts, engines, and engine inlets. The test results substantiated that with the incorporation of adequate deicing and anti-icing systems, the YUH-60 displayed the potential for operating in a moderate icing environment. The production UH-60A incorporates a main and tail rotor blade deicing system, anti-icing systems and an ice detection system. Artificial and natural icing tests are required to qualify these systems for operation in a moderate icing environment. The objectives of this test were:

(1) Phase I. Provide support to the contractor, Sikorsky Aircraft Division (SAD), for final optimization of the production main and tail rotor deicing and anti-icing systems.

(2) Phase II. Conduct artificial and natural icing flight tests of the production UH-60A helicopter to:

(a) Substantiate the effectiveness of the contractor-provided anti-ice/deice systems.

(b) Determine the effectiveness of the ice detection system.

(c) Evaluate the effect of observed ice accumulation on handling qualities and performance. The anti-ice/deice systems will be operating for all tests in the icing environment.

(d) Provide data for inclusion in the Operator's Manual.

b. Late aircraft arrivals to the test site and warning weather trends precluded Phase II testing. This summary addresses only the limited Phase I testing. Testing to satisfy the Phase II objectives are addressed under Project

No. 79-19 and Project No. 80-14. The test aircraft was a production UH-60A, SN 77-22714, equipped with an improved main rotor and tail rotor deicing system, ice detection system and improved anti-icing system. The anti-ice systems are as follows: Two electrically heated pitot static probes; electrically heated pilot and copilot windshields; and bleed air anti-ice heating capability for the engines and engine inlet cowls. Control of the engine and engine inlet anti-ice systems is such that both systems function simultaneously; they cannot be operated independently to evaluate the separate effects of each. The engine inlet cowling anti-ice system was not representative of a normal configuration. With engine inlet anti-ice ON, flow of bleed air to the inlet cowl is normally regulated (modulating valve) as a function of ambient air temperature. Due to valve malfunctioning, this modulating feature was disabled on the test aircraft inlets, and whenever inlet anti-ice was ON, maximum bleed air was always supplied to the inlets regardless of ambient conditions. Subsequently, the modulating valve has been redesigned and component qualified.

c. In-flight simulated icing tests were conducted in the vicinity of St. Paul, Minnesota, from 11 March through 16 March, and 6 April through 10 April, 1979. A total of five (5) icing flights were conducted (7.2 flight hours), of which 136 minutes were spent in the artificial icing cloud. An additional 5.9 flight hours were accumulated while gathering baseline data, seeking suitable test conditions, or inflights not related to icing. Flight limitations contained in the Operator's Manual and in the Airworthiness Releases were observed. Since an OAT below -10°C could not be attained, one of the three required OAT and LWC combinations was not flown, precluding completion of Phase I as planned. With the exception of one flight, all test flights were conducted by SAD as part of Phase I. The test conditions are listed in Appendix B-7.

d. <u>Instrumentation and Cloud Measuring Equipment</u> - In addition to standard aircraft instruments, calibrated instrumentation was installed aboard the test aircraft. Data from the cockpit instrumentation was recorded on flight data cards, and the specially installed instrumentation system on magnetic tape. Appendix C-6 provides a listing of the specially installed instrumentation. A high speed 16mm camera was attached to the outside of the right rear cargo window to view the bottom inboard portions of the main rotor blades inflight. The main rotor blades were marked in ten percent span increments, both top and bottom. Poor design of the camera installation/test setup, and failure to perform fit/functional checks early enough to identify the design setup problem produced unusable results.

e. <u>Ice Protection Systems</u> -

(1) The UH-60A rotor deice system uses the cyclic electrothermal deicing concept as follows: A prescribed amount of ice is allowed to accrete on the blade surface. Sufficient heat is then applied to the surface to break the ice bond, permitting the ice to be shed by the centrifugal force of blade rotation and scavenged away by the airflow. The system uses an opposing blade power cycle, i.e., two blades deiced at a time, thus conserving electric power. The main rotor blade heating elements are embedded in the leading edge sheath and cover 21 to 92 percent spanwise and 12 percent upper to 17 percent lower surface chordwise. These elements are divided into four independent electrical heating zones. Tail rotor blade heating elements are embedded in the leading edge skin and cover 25 to 91 percent spanwise and 12 percent upper and lower surface chordwise. These elements are single electrical heating zones.

(2) The main and tail rotor central circuits operate independently. The main rotor central circuit closes the main rotor contractor and produces a pulse train consisting of eight pulses followed by a waiting period, or off time. The tail rotor central circuit provides an output to the tail rotor contractor coil. Energizing the contractor applies power via the tail slip ring assembly simultaneously to all the heating elements of the tail rotor. Heater element ON time for both main and tail rotor blades is controlled by the controller in response to the OAT sensor. Time between cycles (OFF time) is a function of sensed LWC.

(3) The first icing flight was a 10 minute cloud immersion at -5°C OAT and 0.5 $gm/m^3$ LWC. Post-flight analysis of deice electrical pulse data showed that heater element ON time was different than programmed. The initial pulse of each cycle was shorter than the rest, and the pulse lengths were not of the required duration for the existing OAT. The measured OAT was biased 2°C to 3°C above the actual OAT. This bias accounted for the short pulse lengths, and electrical interference was eliminated by shielding the cable running from the probe to the controller, and disconnecting test instrumentation from the probe. A resistor was added to balance the bias caused by line-length losses and corrected the problem.

e. Ice Accretion and Shedding Characteristics - Ice accretion and shedding characteristics were not reported by USAAEFA while supporting the contractor during Phase I testing.

f. Vibration - No unusual vibration levels were observed or recorded during the limited scope of this test phase.

g. Performance - Performance characteristics were not reported by USAAEFA while supporting the contractor during Phase I testing.

h. Handling Qualities - No unusual handling qualities were observed or recorded during the limited scope of this test phase.

9. USAAEFA Project No. 79-19, UH-60A Natural and Simulated Icing (Reference A-14, Appendix A)

a. The U.S. Army requires that the UH-60A Black Hawk helicopter operate safely in an icing environment through a moderate level of intensity. Artificial icing tests were conducted previously in Alaska in 1976 by USAAEFA using a prototype YUH-60 equipped with a main and tail rotor deice system and anti-icing equipment for the pilot and copilot windshields, pitot-static tubes and support fairings, engines, and engine inlets. Additional limited artificial icing tests of a production UH-60A with similar deice and anti-icing systems installed were conducted in Minnesota in 1979 The production UH-60A incorporated improved main and tail rotor deice and anti-icing systems. Additional artificial and natural icing tests were required to qualify these systems for operational use in a moderate icing environment. The objectives of this test were to conduct artificial and natural icing flight tests of the production UH-60A helicopter to:

(1) Substantiate the effectiveness of the production anti-ice and deice systems.

(2) Determine the effectiveness of the ice detection subsystems.

(3) Evaluate the effect of ice accumulation on the UH-60A helicopter handling qualities and performance.

(4) Provide data for inclusion in the Operator's Manual.

b. Test Scope -

(1) Inflight artificial and natural icing tests were conducted in the vicinity of St. Paul, Minnesota, from 11 February through 31 March, 1980. A total of 31 flights were conducted totaling 52.2 hours. Of these flights, four were in the artificial icing environment, totaling 6.9 hours, and 15 flights were in the natural environment, totaling 30.5 hours. Pressure altitude varied from 1700 to 10,000 feet. Icing was accomplished at ambient temperatures from -4 to -21.5°C at liquid water contents (LWC) of 0.01 to 1.0 grams per cubic meter ($gm/m^3$). Test airspeed in the icing environment was 82 to 138 knots true airspeed (KTAS) and main rotor speed was 258 rpm. Anti-ice and deice systems were operated continuously while in the icing environment. The aircraft was flown in the normal utility configuration and with the IR suppressor kit installed. Specific test conditions are provided in Appendix B-8.

(2) Artificial icing of the UH-60A was conducted by flying in a spray cloud generated by the HISS. Prior to entering the cloud, the test aircraft was stabilized at the predetermined test conditions and baseline trim data were recorded. The test aircraft was then immersed in the spray cloud. Data were recorded every five minutes while in the spray cloud. After a predetermined time of ice accumulation (15 min) the test aircraft was stabilized outside the spray cloud as the initial conditions and trim data were recorded. Ice accretion was documented by photographic and visual observation. When conditions permitted, a steady-state autorotation was performed to determine autorotative main rotor speed with ice accumulated on the aircraft.

(3) Natural icing tests of the UH-60A were conducted by flying in IMC icing conditions. Flights were conducted in accordance with instrument flight rules (IFR). All natural icing flights were conducted within the envelope of outside air temperature (OAT) and LWC previously established in the artificial environment. Close coordination with air traffic control and flight service stations was required to find and stay in the icing environment. In addition to the coordination, a combination of radar vectoring, navigational aid holding, and block airspace assignment was used to stay within the icing environment. Initial natural icing flights were accompanied by a support aircraft, flying in VMC below the clouds. At the termination of the natural icing encounter, the support aircraft crew recorded and photographically documented the ice accumulation. Trim data were recorded upon entry into the icing environment and every five minutes thereafter. When conditions permitted, a steady-state autorotation was performed to determine autorotative main rotor speed with the ice accumulated on the aircraft. Time in the clouds was limited by the availability of the natural conditions and aircraft IFR fuel requirements.

c. Instrumentation and Cloud Measuring Equipment - In addition to standard aircraft instruments, sensitive calibrated instrumentation was installed aboard the test aircraft. Data were recorded on flight data cards and magnetic tape (PCM and FM). The high rotation speed of the tail rotor prevented good photographic documentation of the accretion characteristics. Camera documentation of the ice accretion and shedding characteristics of the stabilator (test aircraft

mounted camera) and the test aircraft airframe (chase aircraft camera) was acceptable for data evaluation. Instrumentation and special equipment is shown in Appendix C-7.

d. <u>Ice Protection Systems</u> -

(1) The UH-60A main and tail rotor blade deice system uses the cyclic electrothermal deicing concept. A prescribed amount of ice is allowed to accrete on the blade surface. Sufficient heat is applied to the surface to break the ice bond, permitting the ice to be shed by centrifugal force and scavenged away by the airflow. The blade deice system components were: a Rosemount outside air temperature (OAT) sensor; a panel mounted on the instrument panel. The system also includes a main and tail rotor slip ring mounted on the main and tail rotor respectively, a blade deice controller, and a main rotor distributor The main and tail rotor blades contained resistive heating mats.

(2) The OAT sensor was mounted on the nose section between the center windshield and the nose avionics door. A shield was installed in front of the sensor to assist in eliminating kinetic heating effects. The OAT sensor supplied a signal to the blade deice controller to set element on time between 1 and 13 seconds for the eight main rotor deice pulses and between 1 and 32 seconds for the one tail rotor pulse.

(3) The UH-60A helicopter deice system was evaluated for operational characteristics and effectiveness during 4.2 hours productive flight time in an artificial icing environment and 20.5 hours productive flight time in a natural icing environment. During testing in the artificial environment, the operating mode of the system (Trace, Light, Moderate) was manually selected as a function of the LWC of the artificial cloud. During testing in the natural environment, the system was operated in the automatic mode. A deice cycle, that is, the period of time from the beginning of a deice electrical pulse to the beginning of the next system pulse, was characterized by an increase in engine torque of 4 to 12 percent and a rise in turbine gas temperature (TGT) of approximately 75°C (para 34). Following this rise in torque, a noticeable increase in longitudinal and vertical vibrations at a frequency corresponding to two cycles per revolution (2/rev) of the main rotor was experienced while the heating pulses were applied to the main rotor blades (para 33). The vibrations then returned to the level prior to the heating pulses being applied to the rotor blades. Following the increase in vibrations, engine torque and TGT returned to their previous values. With collective fixed and altitude held constant, indicated airspeed would decrease up to 12 KIAS during an ice accretion cycle.

(4) During this flight test program, which consisted of 52.2 flight hours, there were six failures of the deice system: one failure of the icing rate meter; two deice system failures associated with the main rotor components; and three deice system failures associated with the tail rotor components. Of the two failures of the main rotor deice system, the first required changing the deice system controller and the fault monitor panel. The second main rotor deice failure was caused by a broken ground wire in the main rotor distributor which resulted in failure of the deice controller. The wire was repaired and the controller replaced. Of the three tail rotor deice failures, one was caused by a broken wire in the tail rotor slip ring. This occurred after approximately 150 hours of flight time on this component. The tail rotor slip ring was replaced. The second failure of the tail rotor deice components was caused by a

worn brush assembly. Again, this component had approximately 150 flight hours. The brush assembly was replaced. The third failure of the tail rotor deice components was caused by a faulty deice controller. The controller was replaced. The poor reliability of the deice system is a shortcoming.

(5) With the exception of the poor reliability, the ice detection system performed satisfactorily under the conditions tested, with respect to detection of icing environment and correlation with accepted icing severity definition.

e. Ice Accretion and Shedding Characteristics -

(1) Ice accreted on the heated surfaces of the main rotor blades was observed to shed in the artificial icing environment. Data collected in the natural icing environment indicated that accumulated ice on the main rotor blades was sufficiently shed to return the engine power required to the preaccretion level. Ice did accumulate on some unprotected main rotor blade surfaces. The most obvious accretions were located on the leading edge of the blade inboard of the heating mat. Approximately 12 spanwise inches of leading edge ice was noted in both the artificial and natural environments. Small ice stalk accretions were observed after rotor shutdown on the lower surface of the blades aft of the protected areas. During the extremely cold (-20°C) artificial icing encounters, high speed photography swept tip caps. Upper surfaces of the main rotor blades aft of the protected areas, and in the reverse flow region, also accreted minimal amounts of ice. There were no significant increases in power required or difficulties associated with these ice accretions or their subsequent shedding from these unprotected areas. At the conditions tested, the main rotor blade ice accretion and shedding characteristics are satisfactory.

(2) As much as 1 1/2 inches of ice accreted on sharp edged components of the main rotor head. Lesser thicknesses of ice were noted on flat surfaces and areas opposite the direction of rotation. There was no evidence of ice accumulation interference with main rotor blade spindle lead/lag or flapping and no evidence of restriction to bifilar motion or blade damper operation.

(3) The main rotor blade droop stops were unprotected and accreted ice in the artificial and natural environments. During a shutdown sequence, the droop stop(s) failed to return to the static position or would incorrectly seat, even following cyclic control manipulations trying to force the droop stops to the static position. Failure of the droop stops to return to the static position is a safety concern to ground personnel.

(4) The main rotor anti-flapping restrainers were unprotected and accreted ice in the artificial and natural environments. Following virtually every icing encounter, the anti-flapping restrainers remained in the fly position during and after shutdown procedure.

(5) The tail rotor blades and hub area accreted ice in a similar manner in the artificial and the natural icing environments. Residual ice accumulations observed after shutdown indicated that complete shedding occurred along the heated portions of the tail rotor blades and little ice remained on unprotected surfaces of the tail rotor blades. Ice accretions of over 1/2 inch in thickness remained on the tail rotor blade pitch change mechanisms and inner hub area after many icing encounters, but did not present any problem either during

operation or during operation or during subsequent shedding. Shed tail rotor ice accumulations impacted the upper surface of the stabilator at the intersection of the tail rotor tip path plane and the plane of the stabilator in the cruise position resulting in almost undetectable stabilator skin dents. For the conditions tested during this evaluation, the tail rotor ice accretion and shedding characteristics are satisfactory.

(6) The ice accretion and shedding characteristics of the stabilator were evaluated throughout the program. Similar formations of ice were observed with the IR suppressors installed during artificial icing and natural icing conditions. With the IR suppressors installed, full span stabilator ice was accreted. These ice formations (as much as two inches thick) and the observed natural ice shedding did not interfere with normal aircraft system operation and did not noticeably degrade the performance of the stabilator.

(7) The airframe ice accretion and shedding characteristics of the UH-60A helicopter were evaluated in both the IR suppressor and standard tail pipe configurations at the specific test conditions. Ice formed on all stagnation areas and sharp protrusions from the airframe. No significant or unusual ice accretion or shedding characteristics were observed and the ice accretion and shedding characteristics are satisfactory for all conditions tested.

(8) Ingestion of airframe and rotor system ice was evaluated throughout this program. Frequent instances of ice particles being ingested into the inlet of the T-700 engines were noted both in the artificial and natural icing environments. Chase aircraft and HISS crew members reported ice leaving the aircraft and being ingested by the engines. High-speed motion picture documentation also confirmed engine ingestion of ice particles at least the size of a quarter. No unusual cockpit engine indications were noted. Daily borescope checks of both engines failed to reveal any compressor damage throughout the evaluation. Large pieces of ice were intentionally shed from the windshield wipers to ensure that particles released in this operational manner would not be ingested in sufficient quantities to damage the engines. At the conditions tested, the engine ice ingestion characteristics of the T-700 engines installed on the UH-60A helicopter are satisfactory.

(9) The ice accretion and shedding characteristics of the M-130 chaff dispenser were evaluated during artificial and natural icing conditions. The M-130 system was not operated during this evaluation. No ice accretions or subsequent sheds were observed which would interfere with the operation of the system during or after an icing encounter. For the conditions tested, the ice accretion and shedding characteristics of the M-130 chaff dispenser are satisfactory.

(10) The ice accretion and shedding characteristics of the ALQ-144 IR countermeasures device were evaluated at the specific test conditions. The ALQ-144 was only installed in the IR suppressor configuration and was not operational. All external components were identical to an operational system. The resulting ice accumulations and subsequent sheds from the ALQ-144 did not adversely affect the operation of the helicopter in either the natural or artificial conditions and shedding characteristics of the ALQ-144 IR countermeasures device are satisfactory.

f. Vibration - The observed and recorded vibration levels at the pilot station did not markedly change during the ice accretion phase of the cycle. During the main rotor deice cycle, the vibration levels at the 2/rev frequency did increase appreciably in all three axes, but were most pronounced in the vertical axis. Little change was noted at any other rotor harmonic. These increased 2/rev vibration levels, although qualitatively noticeable, were of sufficiently short duration to cause little concern. After the flight crew has experienced several icing encounters and becomes familiar with this characteristic, the vibration increase becomes more of an assurance that the system is operating effectively than an annoyance. For the conditions tested, the deice cycle vibration characteristics are satisfactory.

g. Performance -

(1) Level flight performance characteristics of the UH-60A helicopter were also evaluated. These performance characteristics were documented before, during, and after ice accretion on the helicopter. Indicated torque increases of 4 to 12 percent were documented. The 12 percent indicated torque required increase represents a 22 percent increase in power above the power required to fly with the same collective setting with no ice accumulated. Each time the deice system cycled (approximately every four minutes for this example), the power decreased to the no-ice-accreted value set at the beginning of the icing encounter. The 22 percent increase in power above the no ice condition required an increase in fuel flow of 16 percent and a 6.5 percent increase in TGT. Over an entire flight, the average increase in fuel flow would be approximately eight percent for these icing conditions due to ice accretion on the rotor systems. These power fluctuations were particularly disconcerning to the pilot since typically the engine power indications remain steady during collective fixed IFR operations when icing conditions are not encountered. Care must be taken to initially set the cruise power with no ice accreted at a sufficiently low level such that the possible 75°C increase in TGT accompanying the torque rise will not encounter the TGT limiter at 840°C and result in drooping the rotor speed. Rotor droops of three percent were experienced during this evaluation when the power was initially set too high. The approximate eight percent increase in fuel flow will reduce the endurance capabilities of the helicopter by a similar amount and reduce the range capabilities probably by a slightly larger amount.

(2) Engine power loss characteristics with operation of the anti-ice systems were evaluated throughout these tests. The referred engine characteristics of both T-700 engines configured with the -106 and -107 engine inlet anti-ice valves were evaluated. No detectable difference was found between the referred engine characteristics of the IR-suppressed and the standard tail pipe configurations. Of particular interest are the increases in TGT and fuel flow associated with the anti-ice system operation. Typically, an approximate 100°C rise in indicated TGT was observed in the cockpit due to turning on the engine and engine inlet anti-ice as well as the bleed air heater. A slightly lower increase (by approximately 15°C) was observed with -107 engine inlet anti-ice valves installed. The increase in TGT reduced the amount of available engine torque at which continuous TGT limits were encountered. The reduction in maximum continuous power resulted in a 15 to 20 knot decrease in cruise airspeed. Increases in fuel flow of 50 lb/hr were typical at all power settings with anti-ice bleed system actuation. This represents an approximate ten percent increase in IMC (icing) cruise fuel flow which is additive to the performance penalties discussed in the previous paragraph. The installation of

the -107 engine inlet anti-ice valve resulted in only an eight percent rise in fuel flow for the specific conditions evaluated. The large power required increases (para 34) and the large power available losses discussed here will significantly effect the range and endurance characteristics of the UH-60A helicopter. For the conditions tested, there were large decreases in power available with engine and engine inlet anti-ice systems operating.

(3) Autorotational descent performance characteristics were evaluated at selected conditions after icing encounters in both the artificial and natural icing environments. The rotor speeds and descent rates observed after ice accumulations were compared with these parameters under no ice conditions. The maximum decrease in autorotational rotor speed with full down collective observed in the artificial environment occurred after 30 minutes exposure to 0.5 $gm/m^3$ LWC, 15 minutes exposure to 0.75 $gm/m^3$ LWC and 15 minutes exposure to 1.0 $gm/m^3$ at -20°C. All conditions were run consecutively and thus the ice accretion was cumulative. The largest rotor speed last noted was from 105 percent (no ice) to 101 percent with ice. After a natural icing encounter which produced the most increased power required, with the collective fixed, (12 percent increase in indicated torque per engine), an autorotational RPM comparison was made in clear air conditions. The rotor speed was again reduced by four percent from 106 percent nominal no ice to 102 percent nominal no ice to 102 percent rotor speed with ice accreted. No change in autorotational descent rate was noted between the ice free and ice-accreted-on-the-rotor-system conditions. Using the rotor speed information contained in the maintenance test flight manual for trends, it should be possible to maintain the rotor speed within the limits specified in the Operator's Manual with ice accreted even at light gross weight and low altitude conditions. For the conditions tested, the autorotational descent performance characteristics of the UH-60A helicopter following an icing encounter are satisfactory.

h. Handling Qualities - The effect of airframe and flight control surface ice accretion on the aircraft handling qualities was qualitatively evaluated throughout all the icing flights at tested conditions. The evaluation was accomplished by performing typical instrument flight maneuvers with and without ice on the aircraft. No degradation of aircraft handling qualities was noted as a result of aircraft ice accretion.

10. USAAEFA Project No. 80-14, Limited Artificial and Natural Icing Tests Production UH-60A Helicopter (Reevaluation) (Reference A-15, Appendix A).

a. The U.S. Army requires the UH-60A helicopter to operate safely in an icing environment through the moderate level of intensity. Artificial icing tests were previously conducted in Alaska in 1976 by the USAAEFA using a prototype YUH-60 with main and tail rotor deice systems and anti-ice provisions for the pilot and copilot windshields, pitot-static tubes and their support struts, engines and engine inlets. Tests with a production UH-60A with similar deice and anti-ice systems were conducted in Minnesota in 1979 and 1980. The production UH-60A incorporates a main and tail rotor blade deicing system, anti-icing systems, and an ice detection system. Additional artificial and natural icing tests were required to evaluate corrections to previously identified deficiencies and shortcomings. The objectives of this limited re-evaluation were to conduct artificial and natural icing flight tests of the production UH-60A helicopter to verify the correction of deficiencies and shortcomings revealed during 1979-1980 icing tests. The specific items to be evaluated were:

(1) Updated icing rate meter calibration.

(2) Droop stop anti-ice protection.

(3) Updated engine inlet modulating valve installation.

(4) Revised deice system off time schedule.

b. The test aircraft, SN 77-22716, is a production UH-60A with production anti-ice and deice systems. Major differences between test aircraft 77-22716 and the previous icing test (Project No. 79-19) are the engine inlet anti-ice valves; five configurations of droop stops and anti-ice protection; 30 percent shorter off time for automatic deice cycle and a clean configuration (no M-130 dispenser or AN/ALQ-144 IR countermeasures device). The anti-ice systems installed on the aircraft use a variety of methods to provide ice protection. Engine bleed air is used to anti-ice the engine inlet and the engine. Additional engine anti-ice protection is provided by hot engine oil and the inlet particle separator (IPS) which offers limited protection from foreign materials such as ingested ice. Electrical energy is used to anti-ice the pilot and copilot windshields, the pitot tubes, and the struts that support the pitot tubes. Droop stop anti-ice protection is provided by electrically heating the droop stop pivot bolt.

c. Test Scope - Inflight artificial and natural icing tests were conducted in the vicinity of St. Paul, Minnesota, from 22 December 1980 through 24 February, 1981. A total of 19 flights were conducted totaling 32.4 hours. Of the flights, 14 were in the artificial icing environment, totaling 23.2 hours, and three flights were in the natural environment, totaling 5.7 hours. The aircraft was flown in the normal utility configuration with five different droop stop configurations. Average density altitude varied from -1500 to 7780 ft. Icing was accomplished at ambient temperatures from -6.0 to -22.0°C at average liquid water contents (LWC) of 0.25 to 1.0 gram per cubic meter (gm/m$^3$). Test airspeed ranged from 90 to 141 knots true airspeed (KTAS) and the main rotor speed was 258 rpm. A list of the icing test conditions is contained in Appendix B-9. Anti-ice and deice systems were operated continuously while in the icing environment.

d. Instrumentation and Cloud Measuring Equipment - In addition to standard aircraft instruments, calibrated instrumentation was installed aboard the test aircraft. Data from the cockpit instrumentation was recorded on flight data cards, and on magnetic tape by a specially installed instrumentation system. Appendix C-8 provides a listing of the specially installed instrumentation.

e. Ice Protection Systems -

(1) The UH-60A main and tail rotor blade deice system uses the cyclic electrothermal deicing concept. A prescribed amount of ice is allowed to accrete on the blade surface. Sufficient heat is applied to the surface to break the ice bond, permitting the ice to be shed by centrifugal force and scavenged away by the airflow. The blade deice system components were: a Rosemount ice detector (Model 871FF1) mounted on the right engine nacelle; an icing rate meter, a blade deice control panel, and a fault monitor panel mounted on the instrument panel. The system also includes a main and tail rotor slip ring mounted on the main and tail rotor respectively, a blade deice controller,

and a main rotor distributor. The main and tail rotor blades contained resistive mats.

(2) The free air temperature (FA) sensor provides a signal to the deice controller to set heater element on times. The ice detector provides a signal to the ICE DETECTED capsule on the caution/advisory panel and a second signal to the icing rate meter. In the AUTO mode, the icing rate meter provides a signal through the blade deice control panel to the deice controller to set heater element off times according to icing intensity. The deice controller provides the blade element electrical heating elements and, through the main rotor slip rings, to distribute to the main rotor blade's heating elements.

(3) The UH-60A helicopter deice system was evaluated for operational characteristics and effectiveness. During testing in the artificial environment, the operating mode of the system (Trace, Light, Moderate) was manually selected as a function of the LWC since the ice detector was not immersed in the cloud. During testing in the natural environment, the system was operated in the automatic mode. Although the automatic deice cyclic schedule was changed to an approximately 30 percent shorter off time from that previously tested, no evidence of rotor blade ice run back was observed. Even with the shorter element off time tested, indicated torque rises (collective fixed) of 14 percent were recorded with ice accumulation on the rotor system. These indicated torque rises were somewhat higher than the maximum observed torque rises during last year's testing and were attributed to more severe natural icing conditions. All other deice system operational characteristics remained unchanged from previous testing.

f. <u>Ice Accretion and Shedding Characteristics</u> -

(1) As previously reported, all in-flight data indicated clean shedding of the heated portions of the main rotor blades during the deice cycles. Photographic confirmation of this fact was possible throughout the artificial tests. In natural icing conditions, with the collective fixed, the engine torque rise associated with rotor system ice accretion was completely eliminated at the completion of a deice system cycle. During icing encounters (natural and artificial), the crew detected fuselage impact with shed ice particles, principally by sound (thump on fuselage) and by visual means under some lighting conditions (artificial conditions only). Most frequently, ice was shed as the advancing rotor blade approached the aircraft three o'clock position. The trajectory of the shed ice particles caused numerous fuselage impacts which could sometimes be heard in the cockpit. Following each icing encounter, additional dents were documented.

(2) Ice accretion characteristics of the main rotor blade anti-flapping restrainers was evaluated throughout these tests. The anti-flapping restrainers are not anti-iced and are susceptible to continuous ice accretion throughout an icing encounter. Previous testing had identified the failure of the anti-flapping restrainers to return to the shutdown position as a deficiency. During this evaluation, all but two shutdowns were accomplished with the anti-flapping restrainers stuck in the fly position. Gusty wind conditions up to 18 knots were present during some rotor shutdowns. The main rotor blade tip excursions during coast down under such conditions were accomplished with both the droop stops and anti-flap restrainers in the incorrect position. There was no noticeable difference in recorded vibration levels between Project No. 79-19

and this reevaluation phase. For the conditions tested, the deice cycle vibration characteristics are satisfactory.

h. Performance -

(1) Level flight performance characteristics of the UH-60A helicopter were again evaluated. These performance characteristics were documented before, during, and after ice accretion on the helicopter. Collective position was fixed at pre-immersion trim position, altitude was maintained and airspeed was allowed to vary as necessary during the encounter. Indicated torque increases of 4 to 14 percent per engine were observed. In previous testing (Project No. 79-19) observed torque increases were only 4 to 12 percent. Somewhat more severe icing conditions during these tests (combination of temperature, LWC, ice type, etc) were responsible for the higher torque rise observed. The average test conditions were a gross weight of 16,500 pounds, density altitude of 2,540 feet, FAT of - of -11.0°C and LWC varying from 0.2 to 0.4 gm/m³. The 14 percent indicated torque required increase shown represents a 30 percent increase in power above that required at the same collective setting with no ice accumulated. Each time the device system cycled (approximately every three minutes for this example) the power decreased to the clean blade value observed at the beginning of the icing encounter. The 30 percent increase in power above the clean blade condition required an increase in fuel flow of approximately 12 percent and approximately seven percent in turbine gas temperature (TGT). Over an entire flight the average increase in fuel flow would be approximately ten percent for these icing conditions. The approximate ten percent increase in fuel flow will reduce the endurance capabilities of the helicopter by a similar amount and reduce the range capabilities by a slightly larger amount.

(2) Engine power loss characteristics with operation of the anti-ice systems were evaluated throughout these tests. Engine referred characteristics were documented at various ambient air temperatures to fully investigate the effects of the modulating engine inlet anti-ice valve. In general, the power penalty resulting from use of all engine anti-ice systems at a warmer FAT (near freezing) as opposed to very cold (approximately -20°C) was decreased by approximately 25 percent by modulating bleed air to the engine inlet. These decreased losses, although still significant, provide slightly improved (approximately two percent less) fuel flow characteristics and improved (approximately three percent less) referred TGT characteristics at a FAT near freezing. The improved TGT characteristics are particularly important in that the TGT limiter can routinely be encountered at normal IFR cruise conditions in icing conditions due to the performance penalties incurred with activation of anti-ice bleed air systems and the increased power required due to ice accumulation on the rotor systems. The decreased bleed air power losses due to installation of modulating engine inlet bleed air valves, provide a slightly improved fuel flow characteristics and improved power available characteristics at ambient temperatures near freezing.

i. Handling Qualities - No degradation of aircraft handling qualities was noted as a result of aircraft ice accretion.

11. USAAEFA Project No. 76-09-2, Artificial Icing Test Utility Tactical Transport Aircraft System (UTTAS) Boeing Vertol YUH-61 Helicopter (Reference A-16, Appendix A).

a. The U.S. Army requires an improved operational capability in its utility transport aircraft to satisfy the demand for increased performance and survivability in the mid-intensity combat environment. The utility tactical transport aircraft system (UTTAS) was developed in response to this requirement and will replace the current utility helicopter in the Army inventory. USAAEFA was tasked to conduct artificial icing tests of the YUH-61. The overall objectives of the YUH-61 artificial icing tests were as follows:

(1) To provide data to be used for evaluating the ability of the helicopter to effectively operate in moderate icing environment.

(2) To detect, and allow for early correction of, any aircraft deficiencies or shortcomings.

(3) Specific objectives of each testing phase are listed below.

(a) Unheated blade phase:

(1) Evaluate the effectiveness of the windshield, pitot-static, engine air induction, and engine anti-ice systems.

(2) Determine the need for additional anti-ice/deice systems.

(b) Heated blade phase:

(1) Determine the potential effectiveness of the contractor-provided prototype anti-ice/deice systems.

(2) Provide the UTTAS competitors a limited opportunity to further develop anti-ice/deice systems.

The test aircraft, YUH-61, SN 73-21658, was configured with a prototype deice system and anti-ice provisions for the pilot and copilot windshields, pitot tubes, engine, engine inlet fairing, and engine transmission fairing.

b. Test Scope - In-flight artificial icing, utilizing the HISS, was conducted in the vicinity of Fort Wainwright, Alaska, from 9 October through 3 November, 1976. A total of nine icing flights were conducted in 10.6 flight hours, of which 3.2 hours were in the artificial icing environment. The aircraft was iced at test conditions presented in Appendix B-10.

c. Instrumentation and Cloud Measuring Equipment -

(1) In addition to, or instead of, standard aircraft instruments, sensitive calibrated instrumentation was installed aboard the test aircraft and maintained by the contractor. Data were recorded from the cockpit instrumentation and specially installed instrumentation system. Data were recorded on flight data cards and magnetic tape. Selected parameters were observed real time via air-to-ground telemetry. Flight crew comments were recorded on a portable tape recorder. A detailed instrumentation and special equipment list is presented in Appendix C-9.

(2) Cloud measuring equipment included a Rosemount Model 871 FA ice detector coupled to a Rosemount Model 512 P icing rate meter; a Normalair-Garret ice detector coupled to a Normalair-Garrett ice detector indication panel; and a USAAEFA designed and fabricated visual ice accretion probe. An additional Rosemount Model 871 FA ice detector is part of the ice detector system.

(3) The two special instrumentation ice detectors (para 12) were mounted on an unheated structure located between the pilot door and the right gunner window. The location and the unheated structure for attachment were factors which caused inaccurate icing severity indications on both ice detectors at LWC's greater than 0.25 $gm/m^3$. Both ice detectors indicated higher than programmed at LWC's of 0.5 and 0.75 $gm/m^3$.

d. Ice Protection System -

(1) The prototype deice system for the test aircraft consisted of a control system and deice system for the main rotor, tail rotor and horizontal stabilizer components.

(2) The control system consists of a cockpit control panel, a deice controller, an OAT sensor, an ice detector, slip rings, and cabling. Additionally, current transformers are used to monitor system loads. The cockpit control panel contains an ON/OFF switch, an override switch, a test button, and a dual-needle load meter. The deice controller contains the necessary electronics and main power switching contactors to activate the deicing subsystems. The switching contactors sequence the electrical power to the main rotor blade, tail rotor blade, and horizontal stabilizer deicing blankets. The OAT sensor is located beneath the fuselage and provides temperature information to the deice controller. A Rosemount Model 871 FA ice detector is located on the aircraft nose forward to the copilot windshield and provides ice accretion information to the deice controller. Electrical power reaches the main and tail rotor blankets through slip ring and distributor assemblies.

(3) The main rotor blades are fabricated with electrothermal deicing blankets installed as part of the blade leading edge assembly. The heater elements provide a power density of 28 watts per square inch. The heating elements cover the forward 11 percent of the chord on the upper surface at the inboard end, increasing to approximately 12 percent at the blade tip. On the lower surface, the heating elements cover the forward 24 percent of the chord at the inboard end and increase to 25 percent at the blade tip. The heating elements consist of ten blankets on each blade: five major (11 ohms) and five minor (5.5 ohms). A maximum 3-phase electrical load of 21.8 kilowatts is required to deice the main rotor blades.

(4) Each tail rotor blade is protected by a single-element deicing blanket. The blanket covers approximately ten percent of the chord on both sides of the blade along the leading edge. The heating elements provide a power density of 28 watts per square inch. The total tail rotor load of 8.8 kilowatts is carried by two of the three power phases.

(5) An electrothermal deicing blanket is bonded to the leading edge of each horizontal stabilizer. Each blanket consists of a 1-inch-wide cyclically heated deice element on both sides of the leading e[illegible]. When the deice system is operating, a continuous temperature of approximately 150°C is maintained on the parting strip by a temperature sensor and temperature controller. The

electrical power requirement for the two parting strips is 2.15 kilowatts. The deice elements provide a power density of 20 watts per square inch and require a total electrical load of 14.5 kilowatts.

(6) The prototype deice system was evaluated for operational characteristics, electrical switching transients, and electrical power requirements during the heated blade phase. During 2.8 hours of flight time in the artificial icing environment, the deice system automatically cycled 58 times with only two malfunctions. A system cycle consisted of four ice accretion signals from the ice detector, followed by twelve electrical power pulses distributed to the deice system heating blankets. The only component change was the deice system ice detector, which malfunctioned during the first icing flight (para 20). One automatic system shutdown, initiated by the system fault detection circuitry, occurred.

(7) Automatic cycling of the deice system was accomplished by the deice controller, which received an icing signal (pulse) from the system ice detector. The pulse signals were sent from the ice detector when a predetermined thickness of ice was accumulated. The ice detector probe was then readied for another ice accumulation (icing signal) by electrically heating the probe and shedding the ice. During the first icing flight, ice continuously accumulated on the probe due to a failure of the probe heating element; therefore, the ice detector was unable to send repeated icing signals to the deice controller as required for system operation. The system incorporated no provisions to automatically or manually activate the system if the ice detector malfunctioned. Failure of the ice detector heating circuit renders the deice system inoperable.

(8) The deice system contains fault detection logic which deactivates the system and illuminates the ROTOR DEICE caution panel light on the annunciator panel when a fault is detected. One incident of this light illuminating occurred after a cloud immersion of 30 minutes at -16.5°C and a liquid water content (LWC) of 0.25 grams per cubic meter (gm/m$^3$). The aircraft immediately exited the cloud and the deice system ROTOR/STAB switch was cycled OFF and ON. The caution light extinguished and the aircraft reentered the icing environment for an additional 18 minutes (three system cycles) without further incident. The failure could not be duplicated and did not occur during the remaining tests. Post-flight inspection of the system and analysis of the available data indicated an electrical power transient was the probable cause for the momentary system failure.

(9) Within the scope of this test, the electrical power requirements of the deice system were satisfactory. Except for the one failure of the ice detector probe, the Rosemount Model 871 FA ice detector provided accurate icing severity information as correlated with the programmed conditions established by the spray aircraft and the visual probe. Ice accretion and shedding characteristics of the main rotor and tail rotor blades was considered satisfactory; however, the heating capacity of the stabilizer surface was considered inadequate.

e. Ice Accretion and Shedding Characteristics -

(1) To determine ice accretion and shedding characteristics of the main rotor and tail rotor blades and the horizontal stabilizer, the deice systems were not activated during the unheated blade phase. The test technique consisted of two separate cloud immersions. The first immersion was conducted at a

test condition of -12.5°C and 0.25 gm/m³ LWC and was terminated when the visual probe accreted 1/4 inch of ice. Following the first immersion, ice accretion on the main rotor blade and horizontal stabilizer was slight. Increases in power required for level flight (para 35) and autorotational rate of descent (para 38) were observed but did not limit test procedures. Vibration changes of aircraft damage caused by ice shedding were not observed. The second immersion was conducted at a test condition of -13.5°C and 0.25 gm/m³ LWC and was terminated when the visual probe accreted 1/2 inch of ice. Following the second immersion, ice accretion on the main rotor blade leading edge extended from blade station 72 (24 percent radius) to approximately blade station 182 (62 percent radius). The thickness of this ice accretion extended 4 inches aft from the leading edge of blade station 72 (24 percent radius), gradually tapering to zero at approximately blade station 182 (62 percent radius). This ice was very irregular and rough, and varied from 1/2 to 5/8 inch thick. On the main blade lower surfaces, pebbling extended full chord aft from the leading edge between blade stations 72 (24 percent radius) and 130 (44 percent radius). Significant changes in level flight performance (para 35) and autorotational descent performance (para 38) were observed. Ice shedding also caused a change in vibration characteristics (para 33) and airframe damage. During this immersion, ice accreted on the leading edge of the left and right horizontal stabilizer between approximately 50 percent span and the outboard tips. Chordwise accretion was zero at mid span and tapered to eight inches aft at the outboard tips on both upper and lower surfaces. The thickness of the leading edge ice varied from 3/32 inch at mid span to 1/4 inch at the tips. No significant ice accretion was observed on the tail rotor during either immersion.

(2) Random main rotor blade ice shedding was observed throughout the unheated blade phase. No ice sheddings from the horizontal stabilizer were observed. Three incidents of asymmetrical shedding from the main rotor blades occurred during the second flight of the unheated blade phase. Each occurrence was characterized by a moderate lateral airframe vibration (para 33) which lasted approximately one minute. Flight control inputs by the pilot were not required to maintain adequate aircraft control during the asymmetrical sheds. During landing and engine shutdown following this flight, numerous ice particles were observed shedding from the main rotor blades. The ice was shed in all directions and presented a potential hazard to ground personnel in the vicinity of the helicopter.

(3) The ice accretion and shedding characteristics of the main and tail rotor blades and horizontal stabilizer control surfaces were evaluated with the deice system activated. The deice system was activated prior to entering the spray cloud and cycled automatically based on ambient temperature and icing severity. The heated surfaces of the main rotor blades accumulated ice only at conditions of -16.5°C and 0.25 gm/m³. This ice was 1/4 inch wide by 1/8 inch thick and was observed on the leading edge from blade station 116 (39 percent radius) to blade station 161 (55 percent radius). Main rotor blade internal counterweights are located behind the leading edge at the same blade stations. Apparently, these weights were sufficient heat sink to allow accretion of the leading edge ice. Also, a trace of upper surface icing was observed at the same test conditions. The ice accretion pattern on the unheated lower blade surfaces was similar to the accumulations observed during the unheated tests. No run-back and refreezing of moisture from the heated surfaces of the main rotor blades was found during the testing.

(4) Ice accumulation on the heated surface of the horizontal stabilizer were observed at ambient temperatures less than -11°C. The buildups occurred along the outboard 50 percent of the aft edge of the deice boot upper and lower surfaces. The maximum thickness measured was 1/2 inch, tapering to zero at 50 percent span. It appeared that the melted ice had run back to the trailing edge of the deice boot and refrozen. Heated surface icing also occurred at test conditions of -13°C and 0.50 gm/m$^3$ LWC. A 1/2 inch thick accumulation was observed covering the outboard ten percent of the leading edge. At these test conditions, the heating capacity of the surface was inadequate.

(5) No significant ice accretion was observed on the tail rotor blades and hub during either test phase. Factors which may have contributed to this lack of ice accretion were warm engine exhaust air bathing the tail rotor, shallow depth of the spray cloud, and downwash effects of the main rotor disc on the cloud, which reduced the exposure of the tail rotor to the cloud.

(6) The majority of the ice accreted on the airframe occurred in the forward fuselage area. Negligible ice was accreted on the fuselage sides, fuselage bottom, upper fuselage (except the forward crown), engine nacelles, and tail boom. There were two types of glime ice accretion patterns (characteristics) observed. The ice accretion pattern at temperatures warmer than -16.5°C was characterized by a rough surface with numerous irregularities. As the time in the cloud was increased, these irregularities grew in size, forming vertical columns of ice which grouped together to create ice ridges. The ice ridges were most pronounced on the chin bubbles, lower nose area, and pilot foot-steps. The second distinctive pattern was the ice formation at a temperature of -16.5°C, which was characterized by a generally smooth uniform surface with no ice ridge formations. The ice particles on the fuselage were smaller and more numerous, which created the smoother, more regular-texture surface.

(7) Following an immersion of 29 minutes at -13°C and 0.50 gm/m$^3$ LWC, erratic and erroneous ship's system pitot-static indications were observed in level and climbing flight. The first indication of a pitot-static system error was noted during the post-cloud level flight performance test. Random airspeed fluctuations of ±1 to 3 knots were observed on the pilot sensitive airspeed indicator. These airspeed changes were not seen on the copilot production-type indicator. After the level flight performance data were obtained, a climb was initiated at 90 knots indicated airspeed (KIAS) to gain altitude to conduct the autorotational performance tests. As the rate of climb increased to 800 feet per minute (ft/min), the indicated airspeed decreased to approximately 60 KIAS in a level pitch attitude. At a rate of climb of 1000 ft/min, indicated airspeed rapidly decreased to zero. This erroneous airspeed information was received by the SCAS and resulted in an increase in the horizontal stabilizer incidence angle. This caused the aircraft to pitch down and required an aft longitudinal input of approximately 0.5 inch to maintain a level pitch attitude. Cruise guide indicator readings of 100 to 130 percent were observed at rates of climb of 800 and 1000 ft/min, respectively. The pitot-static errors were caused by the thick and irregularly shaped ice accumulations on the fuselage nose and chin bubbles. The ice accretion pattern on the lower portion of the nose was very irregular, with numerous localized buildups of three inches. Ice accumulations of 1-5/8 inches were measured on the chin bubbles in a position which influenced airflow to the pitot tubes in level and climbing flight. The pitot-static system appeared to operate satisfactorily during descents and

autorotation. Pitot-static errors were not observed during climbs with less ice accretion on the forward fuselage area.

(8) The cabin heating system receives outside air for mixing with hot engine bleed air through a circular screened inlet located on the right side of the forward crown. Following a 39 minute flight at -11±C and 0.25 gm/m$^3$ LWC, approximately 90 percent of the heater inlet screen became blocked with ice. No noticeable degradation in cabin heating was observed with the inlet blocked. The ambient air necessary for proper operation could have entered the heater mixer unit through the 1/4 inch gap between the forward crown inlet screen and the mixer unit inlet duct. To preclude automatic shutdown of the cabin heater due to overheating in the mixing unit, an air deflector was fabricated and installed in front of the heater inlet. This deflector kept at least 50 percent of the heater inlet free of ice accretion on subsequent flights.

(9) Operation of the unheated ship's OAT probe was evaluated prior to and during cloud immersion. Maximum ice accumulations of 1-3/4 inches were observed covering 75 percent of the probe surface. No degradation in the OAT probe performance was noted with ice accretion. Within the scope of this test, the ship's standard OAT probe is satisfactory for use in an icing environment.

(10) Minimal ice shedding was observed from ice accumulations on the airframe. Generally, ice which shed from the nose and below the windshields departed the airframe outboard and down, away from the aircraft. Numerous ice sheddings from the windshield wiper arms did occur. These particles ranged in size from 1/2 to 1-1/2 inches in diameter. The trajectory was normally outboard and aft along the fuselage below the engine inlets. One incident of center windshield shedding was observed when the aircraft descended into warmer temperatures. A piece of approximately 3/4 square foot in area departed upward and impacted with the main rotor blades. There was no blade damage and no engine ice ingestion was observed.

f. Vibration - During the heated blade phase of testing, no qualitative or quantitative changes in vibration characteristics were observed during deice system operation or following spray cloud immersion. During the unheated blade phase, the only change in vibration characteristics occurred following asymmetric shedding of accumulated ice from the main rotor blades. The most pronounced change occurred following eight minutes of immersion at -13/5°C and 0.25 gm/m$^3$ LWC when a moderate one-per-rotor-revolution (1/rev) lateral vibration was experienced. This objective vibration subsided approximately one minute later when additional ice was shed from the main rotor blade.

g. Performance -

(1) During the heated blade phase, an increase in engine shaft horsepower (shp) required with ice accretion was noted. The changes in power required were a function of time in the icing environment, ambient temperature, programmed LWC, and change in gross weight due to fuel burnoff and ice accretion. At no time during the testing did the power required to safely operate in an icing environment with all deice/anti-ice systems operating become a limiting factor. However, the level flight performance data show that even with a functioning deice system, a degradation in range and endurance can be expected. Within the scope of this test, a quantitative level flight performance assessment was not made.

(2) During the unheated blade phase, significant power-required increases with ice accretion were noted. A comparison of the heated and unheated phases at similar conditions of temperature and LWC shows that a substantial portion of the power increase was attributable to ice accretion on the main rotor blades. These changes in power required represent a significant level flight performance degradation with ice accretion. The full impact of this degradation on the mission profile was not determined.

(3) Single-engine topping tests were performed to determine the power-available loss with activation of the anti-ice systems. The tests were conducted at three different temperatures by retarding an engine condition level (ECL) to START/IDLE and increasing collective pitch control until intermediate rated power was obtained on the operating engine. The average power-available loss with activation of the anti-ice systems was 250 shp per engine for the conditions tested. This represents 16 percent of the power available, -10°C, sea-level conditions. Within the scope of this test, the engine power-available loss due to activation of the anti-ice systems did not limit flight operations.

(4) During the heated blade phase following a 29 minute immersion at test conditions of -13°C and 0.50 $gm/m^3$ LWC, autorotational rate of descent increased from 2500 to 2950 ft/min. During this phase, the increase in rate of descent was not significant and, within the scope of this test, autorotational descent performance was satisfactory.

(5) During the unheated blade phase following an 18 minute immersion at -13.5°C and 0.25 $gm/m^3$ LWC, there was a significant increase in autorotational descent rate and a decrease in rotor speed with collective full-down. These changes were attributed to a loss of aerodynamic efficiency of the main rotor blades and a fuselage drag increase caused by ice accretion. Based on the progressive degradation of autorotational performance characteristics observed between the two unheated blade phase flights, it was concluded that increased immersion times would cause further rotor speed degradation, such that minimum safe autorotational rotor speed (90 percent) could not be maintained. The aircraft should be restricted from flight in icing conditions when a deice system is not installed and operating.

h. Handling Qualities - The effects of airframe and flight control surface ice accretion on aircraft handling qualities were quantitatively and qualitatively evaluated during both test phases. Quantitative evaluation was accomplished by analysis of level flight control positions measured prior to, during, and following spray cloud immersion. Qualitative evaluation was accomplished during and following spray cloud immersion while performing typical instrument flight maneuvers consisting of cruise, 30 degree bank turns and 500 to 1000 ft/min climbs and descents at 90 knots true airspeed (KTAS). The maximum control position change observed with ice accretion was 4.3 percent (0.3 inch) in the left directional control, which occurred following a 29 minute heated phase immersion at -13°C and 0.50 $gm/m^3$ LWC. This increase in left directional control corresponded to increased power required because of the accreted ice. This change was noticeable to the pilot. There was no significant change in lateral or longitudinal control position. The only adverse handling quality observed during this evaluation was the aircraft pitch-down. No other adverse handling qualities attributable to airframe or flight control surface ice accretion and shedding were observed during either test phase.

12. USAAEFA Project No. 73-04-2, Artificial Icing Tests AH-1G Helicopter (Reference A-17, Apprendix A).

a. The Department of the Army requested that first-line Army helicopters be tested for flight in artificial icing conditions. Coordination was initiated between AVSCOM and the United States Army Alaska (USARAL), to arrange for the conduct of this test program at Fort Wainwright, Alaska, beginning in September, 1973. The Alaska test site was selected to avoid delaying the tests until the CONUS winter months and because of the availability of general maintenance support. Although initial testing of the UH-1H helicopter was completed in Alaska, the AH-1G helicopter artificial icing tests could not be completed at the Alaska test site due to extremely cold temperatures encountered as the winter season progresses. Testing was transferred to and completed at Moses Lake, Washington, during March and April, 1974. The objectives of this evaluation were as follows:

(1) To determine the capability of the AH-1G helicopter to safely operate in an icing environment.

(2) To determine what, if any, problems must be resolved before release of the AH-1G helicopter for flight into known icing conditions.

(3) To provide data which can be used to determine the flight envelope restrictions that should be imposed on the AH-1G helicopter if and when it is released for operational use in icing conditions.

b. The test helicopters were production AH-1G's SN 67-15607 (Alaska) and 67-15844 (Moses Lake) configured with standard AH-1G anti-ice systems and with a nonstandard ice detection system. The Alaska test aircraft had rocket pods installed on the wing store stations for five of the seven test flights. No firings were attempted. The Moses Lake test aircraft was tested in the clean configuration and with a BHC infrared suppressor installed. The standard AH-1G anti-ice system consists of engine inlet anti-ice, engine air screen door operation in conjunction with engine inlet anti-ice, pitot heat, and windshield rain removal. Within the scope of these tests, only the engine inlet anti-ice and the pitot heat were found to be effective at all conditions tested. The AH-1G rain removal system utilizes engine bleed air to evaporate moisture from the windshield. Bleed air is ducted through a vent at the base of the windshield and directed onto the windshield. The system was capable of keeping only a portion of the windshield clear of ice at temperatures of -5°C and warmer. As a result, copilot/gunner (front seat) forward field-of-view was partially obscured and pilot (back seat) forward field-of-view was totally obscured by ice formation at these temperatures. As temperatures were reduced below -5°C, the area of windshield that remained clear was further reduced. Accomplishing visual flight tasks such as nap-of-the-earth flight would be extremely hazardous. Restriction of forward field-of-view due to ice formation on the windshield is a deficiency.

c. Test Scope - In-flight artificial icing tests, utilizing the HISS, were conducted in the vicinity of Fort Wainwright, Alaska, from 22 October through 6 November 1973 and in the vicinity of Moses Lake, Washington, from 22 March through 2 April 1974. A total of 16 icing test flights were conducted consisting of 8.5 productive hours, of which 4.0 hours were in the artificial icing environment. Density altitude varied from 2000 to 10,000 feet. Icing was

accomplished at static temperatures from -4.5°C to -13.0°C and at liquid water content (LWC) levels ranging from 0.25 $gm/m^3$ to 0.75 $gm/m^3$. Tests were conducted in the clean, external stores and IR suppressor configurations. The test airspeed in the icing environment was generally 90 knots indicated airspeed (KIAS) during level flight and 70 KIAS during autorotational descent. A list of test conditions is presented in Appendix B-11.

d. Instrumentation and Cloud Measuring Equipment -

(1) Nonstandard ice detection and measuring devices were used on both test aircraft. A Rosemount Model 871 ice detection and Model 512P Ice Rate Meter was used on both test aircraft. Visual ice accretion indicator probes were fabricated and mounted on each aircraft. The test aircraft at Alaska had one ice accretion indicator probe while the test aircraft used in the Moses Lake tests had two probes. In-flight film coverage of the test aircraft was accomplished using hand-held cameras operated from the chase aircraft on the spray aircraft. A detailed listing and description of the instrumentation and special equipment is provided in Appendix C-10.

(2) Good correlation was observed between the programmed icing severity and that indicated by the Rosemount icing rate meter. Postflight measurements of of ice accretion on the aircraft fuselage were also in close agreement with the programmed levels.

e. Ice Protection Systems - An ice protection system such as rotor blade deice, OAT sensor and an ice detector system were not part of the production AH-1G and, therefore, were not tested.

f. Ice Accretion and Shedding Characteristics -

(1) Measurements of ice remaining on the helicopter after landing were made during the testing accomplished in Alaska. Postflight measurements were not possible during the testing at Moses Lake, due to higher surface temperatures which melted the ice before landing. Application of the currently accepted definitions for icing severity showed that separate areas of the helicopter experienced different icing severities during flight in the icing cloud. The different levels of icing were partially attributed to the fact that the icing cloud depth was insufficient to fully immerse the test helicopter. Additionally, it was noted that on those icing flights which concentrated the icing cloud on the upper fuselage and main rotor, the ice accumulation was much greater on the main rotor blades than on the adjacent fuselage areas or the visual ice accretion probe.

(2) Thickness of ice on the main rotor blades was not constant, but increased with distance from the hub center line, reaching maximum thickness of approximately 40 percent of blade span. Outboard of this point, the thickness gradually decreased to the ice shed point. These observations were made primarily from ground measurements obtained after flight 7, which was flown at -9°C. Surface temperatures on this day were sufficiently cold to allow accurate postflight measurements. The icing severity observed on the main rotor blades did not conform to the currently accepted icing severity definitions. A critical factor in an icing environment is the inability of the pilot to ascertain the amount of ice that has accumulated on the rotor systems. Due to the rotor system rotation within the icing environment, more ice accumulates on the

leading edge of a rotor blade than on geometrically similar objects on the fuselage. It has been noted on numerous occasions that ice accumulations on the visual probe reflecting trace-to-light icing severity were experienced while the leading edge of the main rotor blades accumulated sufficient ice to be categorized as severe. It is recommended that a study be conducted to determine icing severity definitions which more accurately depict icing severity conditions observed on helicopter rotor systems.

(3) Ice shedding characteristics were most influenced by temperature. At test temperatures of -5°C and warmer, ice was continuously being shed from the main rotor system during flight in the icing cloud. The shed point was within four feet of the hub center line and shedding was generally symmetrical. All ice was shed from the main rotor blades outboard of the shed points on all tests. The shed point moved further outboard on the blades as test temperatures were decreased. At -9°C the shed point was approximately 17 (80 percent) outboard from the hub center line and shedding was sporadic and sometimes asymmetrical. At -13°C, ice formed all the way to the rotor blade tips and no shedding was noted until warmer temperatures were encountered when descending to land. Very limited accretions of ice at these conditions prevented asymmetric ice shed occurrences.

(4) Various methods of inducing ice shedding from the main rotor system were investigated. These included flight control movement (cyclic and collective pulses), main rotor speed variation (effected with the use of the rpm increase/decrease switch), and the application of two commercial anti-ice aerosol sprays to the rotor blades prior to flight (XIM Spray by X-I-M Products Inc., Westlake, Ohio, and Icephobic Cationic Glaze (ICE) Spray by the Vortex Company of Palo Alto, California). Although no method was found to be consistently effective, varying main rotor speed proved to be the best method of inducing main rotor ice shedding. This method lost effectiveness at temperatures colder than -5°C and was totally ineffective at temperatures below -10°C. Cyclic and collective pulses were found to be ineffective, with very little ice shedding noted even at the warmer temperatures. The commercial anti-ice aerosol sprays (normally used to induce ice shedding from fixed wing aircraft) were evaluated during flight 11. Ice shedding characteristics were unchanged during the flight. Application of the sprays was ineffective in inducing main rotor ice shedding and their use was discontinued.

(5) Ice shed from the main rotor system during flight struck the canopy and fuselage on numerous occasions; however, no damage was found during postflight inspections. High-speed photography showed ice being shed from the main rotor and fuselage in a random fashion, especially at temperatures of -5°C and and no evidence of structural damage of the tail rotor blades was found.

(6) Only limited test data was gathered on the ice accretion of the tail rotor as primary objectives were the fuselage and rotor disc ice accretion and shedding characteristics. Ice accretion up to 3/16 in. were recorded on the tail rotor blades with the majority of the ice accretion on the tail rotor system deposited on the pitch change links and the hub area. As no increase in tail rotor vibration levels were noted, it was believed that tail rotor blade shedding was symmetrical within the scope of these tests.

(7) Ice accumulation on forward surfaces of the canopy were recorded due to the deficiency of the AH-1G rain removal system to keep the windshield

clear of ice at temperatures below -5°C (para 5). Ice formations up to one inch on the leading edge of the engine air screens prevented the screens from completely closing.

(8) Ice formation on the ECU air inlet screen caused total blockage of the cold air inlet at all test temperatures. Cockpit heating was never attempted during this program, due to the requirement for the rain removal system to be ON (thus precluding use of cockpit heat). It is probable that blockage of the cold air inlet screen would cause much higher temperatures in the ECU ducting which would cause the over-temperature safety switch to activate and shutdown the heating system. Ice accumulation on the ECU cold air inlet screen, causing total blockage, is a shortcoming.

(9) The Alaska test helicopter was configured with M159A1 seven-tube 2.75 inch rocket launchers installed on each wing store during a portion of the flight tests. The inboard pods were loaded with inert rockets and the fronts of the outboard pods were blocked by metal plates to aerodynamically simulate a full load of rockets. Ice accumulation on the faces of the 2.75 inch rockets of over one inch in thickness were documented after flight in programmed moderate icing conditions. Ice accumulations of 1/2 inch in thickness were also noted on the AH-1G turret; however, turret movement was in no way degraded. Firing of the rockets or the turret weapons was not attempted during these tests. Ice accumulations on the AH-1G canopy restricted use of both the pilot M73 reflex sight and the gunner sighting station.

(10) A BHC IR suppressor system was installed on the Moses Lake test helicopter on seven of the nine test flights. External modifications to the helicopter for installation of the IR suppressor system included two inlet assemblies (right side and left side), a tail pipe fairing, and an exhaust duct.

(11) In-flight observations indicated that icing characteristics of the vertical fin and tail rotor area were improved due to the installation of the IR suppressor system. No ice was observed to build on the tail rotor system or the adjacent portions of the vertical fin with the IR suppressor system installed.

f. <u>Vibration</u> -.

(1) The 1/rev vibration levels greatly increased in all axes of all monitored stations during flight with an asymmetrical ice loading on the main rotor blades. The 1/rev vibration levels at the tail rotor 90-degree gearbox station showed a much greater increase in the aircraft lateral and longitudinal axes than in the vertical axis during flight with an asymmetrical ice loading on the main rotor blades.

(2) Increased vibration levels were qualitatively noted during eight of the sixteen test flights. During flight 12, moderate 1/rev vibration levels were qualitatively assessed, with individual vibration encounters lasting approximately 30 seconds. During flight 15, the 1/rev vibration level was qualitatively noted to increase in three distinct steps which occurred over an approximate five minute time interval. The third, and most severe, vibration level reached during this flight continued for approximately two minutes. The severe vibrations caused crew discomfort, adversely affected the pilot's ability to read the flight instruments, and required considerable pilot compensation to maintain aircraft control.

(3) Upon completion of the icing tests at Moses Lake, a thorough inspection of the test helicopter revealed that the transmission mounts had worn beyond the serviceability standards set forth in the maintenance manual. These mounts had been inspected and found to be within limits just prior to the icing tests. The damage was attributed to excessive loads imposed by the higher vibration levels encountered during the tests.

g. Performance -

(1) A limited level flight performance evaluation of the AH-1G helicopter was conducted. Level flight performance was significantly degraded as ice was accumulated on the main rotor blades. After ten minutes in the cloud on flight seven in programmed light icing at -9°C, a 40 percent increase in engine power was necessary to maintain level flight. On flight 16, in programmed moderate icing at -11°C, a four minute icing interval resulted in a 25 percent increase in power required. The degradation in level flight performance associated with ice accumulation on the main rotor blades would significantly reduce range and endurance. An accurate quantitative assessment of the degradation of level flight performance was not practical because of the constantly changing conditions of the ice on the rotor blades (i.e., ice building on the blades or shedding from the blades).

(2) Autorotational descent performance was degraded as ice accumulated on the main rotor blades. The degradation of autorotation descent performance was evidenced as an increase in the stabilized autorotational rate of descent and a decrease in the stabilized autorotational rotor speed obtainable. The largest increase in stabilized autorotational rate of descent observed during these tests occurred during flight five in which a 540 foot per minute increase in stabilized autorotational rate of descent was observed during an autorotation after 15 minutes of flight in the artificial icing environment at -9°C. The stabilized autorotational rotor speed of 330 rpm. The largest decrease in autorotational rotor speed observed during these tests occurred during flight seven. The autorotation performed during this flight was terminated before a stabilized rotor speed was reached in order to prevent further decay of rotor speed below the safe operating limit (294 rpm) stipulated in the Operator's Manual. It is not known how far the rotor speed would have dropped if a power recovery had not been made. The rotor speed was still dropping rapidly when power was applied to arrest the decay. Although no stabilized descent rate could be established, pilot comment indicates that rates of descent in excess of 4,000 feet per minute were observed on the pilot's vertical speed indicator.

h. Handling Qualities - The pilot's comments and recorded control position data showed no apparent changes in the handling qualities of the helicopter with ice accumulation. Within the scope of this test, except for the degradation of handling qualities associated with increased vibration levels, the handling qualities of the AH-1G helicopter were not adversely affected by ice accumulation.

13. USAAEFA Project No. 81-13, Support of Bell Helicopter Textron Icing Certification Effort of the 214 ST Helicopter (Reference A-18, Appendix A)

a. Bell Helicopter Textron (BHT) conducted testing to certify the 214 ST helicopter to fly into a forecast icing environment. USAAEFA was directed to provide flight support for BHT to evaluate the 214 ST and associated anti-

ice/deice systems in the artificial icing cloud provided by the HISS.

b. The test helicopter was a prototype Model 214 ST, N214 BH, Bell Helicopter Textron, Inc., S/N 18401.

c. Test Scope -

(1) The evaluation lasted from 22 February to 22 March 1982. A total of 15.2 hours of HISS time with approximately 6.5 hours of actual cloud time were flown. The testing was conducted in St. Paul, Minnesota. All flights were artificial icing tests conducted in VFR conditions. A list of the test conditions is contained in Appendix B-12.

(2) BHT ferried the aircraft to St. Paul, maintained the aircraft, and operated the aircraft. The USAAEFA provided the HISS, support aircraft, and some training and standardization for the BHT flight crew. Four flights (two for each BHT pilot) were conducted with USAAEFA pilots at the controls of the 214 ST. After that, BHT flight crews were on-board the 214 ST.

d. Instrumentation and Cloud Measurement Equipment - The Armys JU-21 configured with FSSP, OAP, Cambridge Hygrometer, sensitive Rosemount OAT, Leigh MK-12 icing rate meter, and data reduction hardware was used to document the test conditions. The CH-47 was equipped with sensitive OAT, hygrometer, and flow rate data to backup the JU-21. The 214 ST was instrumented to document standard performance and handling qualities. Photo documentation was used from the JU-21, 214 ST, and rear of the CH-47. In flight, video monitor of engine inlets was accomplished by a camera at the mouth of the inlet and a monitor in the cockpit.

e. Ice Protection Systems -

(1) The test aircraft was configured with an ice protection system consisting of:

(a) Main rotor and tail rotor deice systems.

(b) Heated pilot and copilot windshields.

(c) Heated engine bellmouths.

(d) Elevator deicing boots.

(e) Leigh and Rosemount icing condition detectors.

(f) Teddington ice detector.

(1) The main rotor blades were constructed with internally mounted heater blankets with the blades divided into seven zones (six equal zones plus the blade tip cap). The tail rotor blades were constructed similarly to the main rotor blades with the exception, that in lieu of heating separate zones on each blade, the entire blade length was heated.

(2) The controller for the main rotor and tail rotor is designed to interpret the OAT and the analysis of LWC from either the Rosemount or Leigh

icing detectors. From the LWC information, the controller set the "off time" or time that ice was allowed to accumulate. The "on time" was a function of the OAT, and the amount of heat rise required was directly proportional to the surface temperature of the blades.

(3) The pilot windshield was replaced by a special windshield which had 67 percent longer area of heating than the standard windshield. This modification was installed as a safety factor as special problems of field-of-view were visualized when flying trail formation behind the HISS.

(4) The electrically heated engine inlet bellmouths are standard equipment for the Model 214 ST and are activated by switches in the cockpit or when surface temperatures fall below 43°F.

(5) The standard elevators of the Model 214 ST were equipped with air-actuated rubber boots. The boots were inflated by engine bleed air on one or three minute intervals as selected in the cockpit. The boots cover approximately 29 percent of the chord on the upper surface and 25 percent of the chord on the lower surface.

(6) Ice detection systems manufactured by Leigh and Rosemount were installed in the test aircraft prior to the start of test. Engine bleed air was supplied to both probes to assure aspiration at hover and low airspeeds, and since the air is hot, keeps both probes ice free. Valves located in the cockpit overhead allow either or both probes to be isolated as required, although neither probe uses enough bleed air to cause a significant change in the engine measured gas temperature (MGT). An icing output signal was made available from both systems into the main rotor/tail rotor deicing control. Based on this information, the DCC controller chose an "off time" or time allowed for ice accretion. A switch was made available that permitted a selection of either detection system as a source signal to the controller. It should be noted that neither system was utilized for the automatic mode during the tests reported herein; therefore, the compatibility and adequacy of either system are not known.

(8) A Visual Teddington ice detector was mounted on the pilot's door. This detector permitted a ready observation of ice accumulation, including a light for night flying and a heating element for removing ice. The system had a breakaway connection for easy door removal.

f. Ice Accretion and Shedding Characteristics, Vibration, Performance, Handling Qualities - Engineering data, results, and analysis were retained by Bell Helicopter Textron and are not available for this report.

14. USAAEFA Project No. 80-08, YAH-64 Icing Survey (Reference A-19, Appendix A).

a. The U.S. Army required the AH-64 helicopter to operate safely in an icing environment up to and including the moderate level of intensity. Artificial and natural icing tests were required to substantiate airworthiness qualification of the systems for operation in icing conditions through the moderate level of intensity. USAAEFA and Hughes Helicopters conducted joint artificial and natural icing tests of a prototype rotor blade deicing system, anti-icing systems and ice detection system installed on the YAH-64. The HISS was

configured with a total of 97 Sonic Development Corp. Sonicore Model 125-H nozzles installed on the two center sections. A 150 foot standoff distance was used which resulted in an eight feet deep by 36 feet wide spray cloud. Test conditions are listed in Appendix B-13a and B-13b. The purpose of this test was to:

(1) Determine the effectiveness of the YAH-64 ice protection and detection systems.

(2) Determine the impact of ice accumulation on performance and handling qualities.

(3) Determine the capability of the YAH-64 and associated subsystems to operate in moderate icing conditions.

b. Instrumentation and Cloud Measurement Equipment - The test instrumentation consisted of the standard aircraft instruments plus those calibrated instruments and recording devices listed in Appendix C-11. Data was recorded on flight card and on magnetic tape.

c. Ice Protection Systems - Both anti-ice and deice systems were installed on the aircraft during the tests. The deice system consisted of an outside air temperature sensor, ice detector, icing rate meter, blade deice controller. The main and tail rotor blades contained electrothermal resistive heating mats. Anti-ice systems were provided for sections of the windscreens, pitot-static tubes, air data sensor, engines, engine inlets, nose gearbox and cross shaft fairings, target acquisition and designation system, and the pilot night vision system. Deice capability was also provided for one of the hellfire missiles.

d. Ice Accretion and Shedding Characteristics -

(1) The YAH-64 APACHE helicopter, with the anti-ice and deice systems installed for this artificial icing program, demonstrated an excellent potential for operating in an icing environment. Many of the systems were successfully demonstrated. A total of ten problem areas were identified, the most important of which were:

(a) The susceptibility of the main rotor blades to incur damage by impact with shed ice particles.

(b) Incomplete system integration of the automatic outside air temperature input to the rotor deice system.

(c) Poor performance of the anti-ice system for the target acquisition and designation/pilot night vision system.

(d) The lack of an icing rate system calibration.

(2) Rotor System Deice. The YAH-64 helicopter deice system was evaluated for operational characteristics and effectiveness during 5 hours and 48 minutes flight time in an artificial icing environment. During these tests, element ON time was established using an outside air temperature (OAT) input which was manually set by the copilot/gunner (CPG) corresponding to the actual OAT as measured by calibrated flight test instrumentation. The ON time schedule was the nominal design line. System OFF time also conformed to a design line

and was also manually input by the CPG as a signal equivalent to the icing spray cloud measured LWC. Element ON and OFF times were not varied since test results indicated satisfactory operation using the system design schedules. No evidence of runback was observed during or following any of these tests. No residual ice accretions were observed on the tail rotor protected surfaces. Although some residual ice was photographed on the main rotor blade protected surfaces, no objectionable aircraft vibration or problems were noted. At the higher LWCs (0.75 and 1.0 gm/$^3$) and the lowest temperature (-20°C), noticeable but not annoying overall vibration levels (VRS 4) were noted at both cockpit stations. Effective main and tail rotor blade ice shedding characteristics were experienced at these artificial icing test conditions using manual scheduling of system ON and OFF times. The YAH-64 rotor system deice operational characteristics should be evaluated in natural icing conditions over the temperature and icing type.

(3) Throughtout these tests, manual input of the OAT was required because the automatic OAT subsystem would not interface with the deice system controller. Because the air temperature can change rapidly in clouds, the lack of automatic OAT sensing prevented system evaluation in the natural icing environment. Fully automatic OAT sensing and system integration required further contractor changes and demonstration and is a significant problem area.

(4) The ice detection subsystem consisted of a Rosemount ice detector mounted in the left engine inlet and an icing rate meter located on the pilot's instrument panel. The size of the HISS cloud precluded fully immersing the ice detector in the artificial icing cloud when the rotor was immersed, and therefore prevented it's evaluation. Historically, this type of icing rate sensor does not demonstrate repeatable or accurate sensing in the artificial icing environment.

(5) The engine inlet cowling ring was anti-iced using hot engine bleed air and was activated by the same engine inlet anti-ice switch discussed in paragraph 7b, above. The cowl ring anti-ice surface temperature and anti-ice characteristics were evaluated throughout the artificial icing tests, as well as during clear air flights. Low engine power settings result in inlet cowling ring surface temperature at or below freezing and may result in ice accumulation if these conditions exist for a period of time.

(6) Nose Gearbox and Cross Shaft Fairings. The nose gearbox and cross shaft fairings were anti-iced electrically using embedded heater elements in the Kevlar material. For this test, the system wad activated by setting a circuit breaker on the overhead circuit breaker panel. Surface temperatures were recorded throughout the artificial icing tests as well as during clear air tests. Fairing surface temperatures varied from 26°C at high airspeeds and cold temperatures (120 KIAS, -20°C) to 38°C at near freezing temperatures and low airspeeds. Ice accretion on the heated surfaces was noted as stated below. Poorly fitted fairings allowed ice to collect on the sharp edge of the fairing. Although no engine ice ingestion damage occurred during this program, the potential exists.

(7) Two panels of the cockpit windscreens were anti-iced electrothermally. The windscreen temperature was regulated to approximately 85°F (29°C), which kept the heated areas ice free throughout these tests. The

CPG windscreen was occasionally obscured in the icing environment by liquid water, requiring windshield wiper operation. All other canopy panels remained free of ice in the artificial icing environment.

(8) The dual, wing mounted pitot tubes were anti-iced electrically and controlled by a single PITOT HEAT switch located on the lower left subpanel. The pitot heat was activated for all flights in icing conditions. No ice accretion was observed and the system operated without failure.

(9) Air Data Sensor (ADS). The ADS was located above the main rotor attached to the standpipe through the main rotor mast. Only the rotor portion of the omni-directional low airspeed sensor was electrically anti-iced. Control of the anti-ice function of the system was through the same switch as the pitot heat. During one flight at -20°C, a "halo" shaped ice ring formed around the center portion of the ADS rotor which, upon shutdown, fell down around the static portion of the ADS mast. This ice froze in position thus preventing further rotation.

(10) The target acquisition and designation/pilot night vision system (TADS/PNVS) anti-ice provisions included window, window frame and selected turret surface panel heating. Mechanical problems (unrelated to icing tests) with the TADS turret prevented slewing for most flights. Residual ice accretions following flight ten (46 minutes at -16°C and 1.0 $gm/m^3$ indicate potential problems with TADS turret full slew capabilities. Residual ice on flight eight caused restrictions in PNVS turret slew capabilities and jammed the turret to a fixed position during the icing encounter.

(11) The YAH-64 anti-ice systems were evaluated for operational characteristics and effectiveness during rotor and fuselage artificial icing exposures of 5.8 and 4.7 productive flight hours respectively, as well as 2.8 hours of clear air testing. Anti-ice systems on the YAH-64 helicopter protect the engine, engine inlet cowling (bleed air), nose gearbox and cross shaft fairing, windshield, pitot tubes, and air data sensor (ADS). All anti-ice systems were activated prior to entering the icing environment and were operational for all icing flights.

(12) Engine anti-icing was accomplished by a combination of hot axial compressor discharge and heat transfer from the air/oil cooler in engine frame. The system was controlled by one engine inlet anti-ice switch located on the pilot's lower left subpanel. The engines were visually inspected (including borescope) daily, and an engine health indication test (HIT) was performed prior to every flight. No engine deterioration was noted during this program. There were no indications of ice accumulation in the engine. The engine anti-ice system demonstrated satisfactory operation in the artificial icing environment.

(13) The electrical power requirements for the deice and anti-ice systems were evaluated throughout these tests. The initial starting values (first 25 seconds) were recorded during these tests.

(14) Flight control surface ice accretion and shedding characteristics were evaluated throughout these artificial icing tests. No in-flight or post-flight difficulties associated with flight control surface ice accretion or shedding were identified.

(15) Ice that accreted on the heated surfaces of the main rotor blades was shed during flight in the artificial icing environment. Minimal amounts of ice accumulated on unprotected surfaces and components of the main blades. Specifically, ice formed on the blades inboard of the heater mats on the blade retention mechanisms. These accretions were small and should not present a significant problem either from accretion or subsequent shedding.

(16) Ice as much as 3/4 inches thick accreted on sharp edged components during most icing exposures. Lesser thicknesses of ice were noted on flat surfaces (low catch efficiency) and areas opposite the direction of rotation. No restriction to motion of any movable component on the main rotor head was noted. Environmental conditions at the test site precluded flight in temperatures above freezing after an artificial icing encounter.

(17) The tail rotor blades and hub area accreted ice in a manner similar to the main rotor system. High speed still and motion picture photography documented ice shedding from the protected portions of the tail rotor blades. Residual ice accumulations on unprotected portions of the tail rotor blades and hub area were noted but no difficulties were associated with these accretions.

(18) The ice accretion and shedding characteristics of the stabilator were evaluated throughout the program. No problems were identified due to these accretions.

(19) The airframe ice accretion and shedding characteristics were evaluated in an artificial icing environment. Ice formed on all stagnation areas and sharp protrusions from the airframe. Two potential problem areas were identified: large ice formations accreted on the canopy frames which shed and caused damage to the main rotor blades, and the CPG's windshield wiper system performed poorly.

(20) The fuselage ice accretion and shedding characteristics were specifically evaluated during five artificial icing test flights. Large accumulations of ice were noted on the wing leading edges, nose, steps, handholds, landing gear, landing gear struts, tail wheel, vertical stabilizer/tail rotor pylon leading edge and many other surface irregularities on the fuselage. No operating difficulties were identified due to these ice accumulations. All windows, doors and access panels remained functional after these icing encounters. Environmental conditions at the test site precluded evaluation of the shedding characteristics of the largest accumulations of ice.

(21) All window panels except the two electrically heated forward facing windows discussed above were unprotected from ice accumulation. During flight in the artificial icing environment, little ice accreted on these unprotected window areas. A slight amount of ice crystals were observed on an area of about 1/2 square foot directly above the pilot's head. This area is not used extensively for critical outside reference and these accumulations were not considered significant.

(22) The framework supporting the essentially flat plate canopy was not anti-iced. The forward-most canopy frames accreted large quantities of ice. Supercooled water droplets which impinged upon the heated glass in some cases pooled on the window and the windshield wiper was used to aid removal. This

water and the normally accreted ice combined (particularly around the CPG window) to form significant sized hard ice accumulations. During at least two flights, these ic rmations became large enough to be broken away by free stream air.

(23) Some of these ice particles were observed to go through the main rotor system and strike the blades. Subsequent ground inspection of the main rotor blades revealed skin damage to a total of four rotor blades, one requiring replacement, one requiring repair and two eventually leading to skin bonding voids requiring repair. This type rotor blade impact with shed ice particles can be expected (even if no canopy frame ice were present) as the aircraft descends below the freezing level and ice from all locations departs the aircraft.

(24) Frequent use of the installed windshield wiper system was required when flying behind the spray aircraft, particularly on the CPG windshield. The angle of incidence of this window relative to free stream air flow allowed for greater amounts of water impingement. The shallow angle of the pilot's window appeared to make it less susceptible to liquid water pooling effects. Various wiper tensions were evaluated indicating that considerable force was required to keep the wiper blade in contact with the windscreens at the higher cruise airspeeds (greater than 100 KIAS). The canopy frame ice immobilized the windshield wipers by freezing them to the canopy frame on several occasions.

(25) Ingestion of ice shed from the airframe and rotor system was evaluated throughout this program. Frequent instances of ice particles entering the inlet of the T-700 engines were noted in the artificial environment. Chase aircraft and HISS crewmembers reported ice leaving the aircraft and entering the engine inlets. No unusual cockpit engine indications were noted. Daily borescope inspections of both engines failed to reveal any compressor damage throughout the evaluation.

(26) The ice accretion and shedding characteristics of the aircraft antennas were evaluated throughout these tests. Many YAH-64 antennas are flush mounted and thus accrete little, if any, ice. Exceptions to this re the transponder antenna located on the cabin overhead and the two forward facing radar warning antennas located on the forward end of each forward avionics bay. No degradation in aircraft radio transmission or reception was noted on any communications or navigation radios, although no specific tests were conducted to evaluate these characteristics. Ice shed from these antennas presented no operational difficulties.

(27) The ice accretion and shedding characteristics of the M-130 chaff dispenser were evaluated throughout these tests. Two dispensers were installed on the test aircraft, one on each side of the tailboom. The M-130 system was not operated during this evaluation. No ice accretions or subsequent sheds were observed which would interfere with the operation of the system during or after an icing encounter.

(28) The ice accretion and shedding characteristics of the dummy ALQ-144 IR Countermeasures device were evaluated. The dummy device was approximately the same shape as an ALQ-144 and was located just aft of the main rotor mast on the top of the fuselage. This location offered the advantage of masking some of the ice particles which would normally impinge and accumulate on the

forward surfaces of the device. The resulting accumulations did not adversely effect the operations of the aircraft.

(29) Ice was accreted on the dummy hellfire missiles and launcher racks. Ice was accumulated only during the fuselage icing encounters. All sharp edges and stagnation points on the missiles and launcher racks accreted ice. Missile deice tests were conducted using a frangible glass dome. The ice formations at the forward end of the missile launcher restricted the arming switch and prevented in-flight arming of the hellfire launcher.

(30) Following artificial icing exposures of the fuselage (5 flights), the wing pylons which are articulated in pitch, were moved through the full range of travel. No restrictions of pylon travel was detected for any of these conditions.

(31) The ice accretion and shedding characteristics of the 30mm chain gun area weapon system were evaluated. Ice accretion on all stagnation points and sharp edges. No weapons firing was accomplished following ice immersion. Although no gun operations were accomplished, the accreted ice did not appear to hamper the mechanical traversing operation of the weapon. The gun was traversed in-flight through its full range in azimuth and elevation to verify unrestricted motion. For these flights, a muzzle protector was fitted to the weapon which accreted up to 1 1/2 inches of ice.

(32) Rocket launchers for the 2.75 inch folding fin aerial rockets were installed for one flight. Forward facing protective covers were installed. These covers were made of a thick, black plastic material and appeared to be very durable. Ice accreted on protective covers installed on the rocket launchers during one fuselage icing flight (flight 12).

e. <u>Performance</u> -

(1) An attempt was made to document level flight performance degradation with ice accreted on the rotor systems and/or on the fuselage, as compared with a non-iced aircraft. No useful information was obtained from these tests because of the large power excursions required to fly formation in the HISS spray cloud, and the long periods of time that elapsed between recording the clean aircraft base line data and the iced aircraft data. Historically, other artificial icing test programs have obtained little useful information from this type test.

(2). The engine performance characteristics were recorded with the anti-ice bleed air systems OFF and ON for comparison. Over a relatively wide range of power settings, including typical cruise power requirements, the increase in fuel flow resulting from activation of the engine inlet anti-ice system was approximately eight percent. This increase in fuel flow will decrease the range and endurance capabilities of the YAH-64. An approximate 40 degree Celsius increase in turbine gas temperature was observed with anti-ice system use. The power available losses (observed throughout these tests) with activation of the anti-icing systems are significant and performance information must be published for the pilot to use in preflight planning.

(3) An attempt was made to document any significant autorotational descent performance degradation caused by residual ice accreted on the rotor

systems of the YAH-64. At no time during this evaluation was an rpm decay of greater than three recorded when the iced rotor autorotational rpm was compared to the clean rotor case at the same airspeed and collective pitch. The ice formations in the artificial icing conditions tend to produce less drag than some icing types found in natural conditions.

f. Handling Qualities - The effect of airframe and flight control surface ice accretion on the aircraft handling qualities was qualitatively evaluated throughout all the icing flights. The evaluation was accomplished by performing typical instrument flight maneuvers with and without ice on the aircraft. No degradation of aircraft handling qualities were noted as a result of aircraft ice accretion in the artificial icing environment.

g. Vibration - The aircraft vibration characteristics were monitored throughout these evaluations. Qualitative pilot and CPG comments were compiled during the artificial icing immersions and flights to home base with residual ice still accreted. The observed and recorded vibration levels at the crew stations did not markedly change for most icing conditions. At -15°C and colder, and liquid water contents of 0.75 gm/m$^3$ and higher, a noticeable but not annoying increase in overall airframe vibration levels was observed (VRS 4). Vibration summary plots (obtained during an artificial icing encounter) for the pilot and copilot crew stations were made. Comparative spectral plots of vibrations at the pilot station were also made with and without rotor system ice accretion.

15. USAAEFA Project No. 73-04-07, Artificial Icing Tests AH-1Q Helicopter(u) (Reference A-20, Appendix A).

a. The objective of this evaluation was to identify any icing characteristics of the AH-1Q helicopter which may be different than those known to exist for the AH-1G helicopter. Based on the tests conducted on the AH-1G helicopter during the fall of 1973, aircraft weapons systems may require ice protection to safely operate after exposure to icing conditions. In view of this information, USAAEFA conducted a limited evaluation of the AH-1Q helicopter weapon system in an icing environment. The icing test of the AH-1Q was conducted on 3 January, 1974. One flight was conducted consisting of 1.0 productive hour, of which 0.4 hour was in the artificial icing environment. Specific test conditions were: pressure altitude of 5000 feet, outside air temperature (OAT) of - 6°C to -4°C and indicated airspeed of 90 knots.

b. Instrumentation and Cloud Measurement Equipment - The instrumentation list and list of special equipment is presented in Appendix C-12. The liquid water content (LWC) and water droplet size in the cloud could not be determined due to a malfunctioning flow rate meter. The maximum ice accretion on the fuselage correspond to moderate-to-heavy icing conditions defined as:

(1) Moderate icing: Accumulation of 1/2 inch of ice on a small probe each 20 miles. On the airframe, the rate of accretion is excessive, making even short encounters under these conditions hazardous. Immediate diversion is necessary or use of deicing equipment is mandatory.

(2) Heavy icing: Accumulation of 1/2 inch of ice on a small probe each ten miles. Under these conditions, deicing equipment fails to reduce or control the hazard and immediate exit from the icing condition is mandatory.

c. Protection Systems - No ice protection systems were installed on the TOW sight unit (TSU) or the TOW missile launcher racks.

d. Ice Accretion and Shedding Characteristics -

(1) After 20 minutes in the icing cloud and approximately one inch accumulation of ice on frontal portions of the fuselage, the test aircraft was removed from the cloud and photographed from the chase aircraft. A landing was made at a nearby airfield, with ambient temperatures below freezing (-2°C), in order to document the ice accumulation on the TOW components with photography.

(2) Two deficiencies were associated with the TSU in an icing environment: obscured vision through the TSU, and immobilization of the TSU turret. Further testing is recommended to determine if the ice buildup in the launcher tubes would interfere with a missile launch.

(3) The TOW missile system was evaluated in an icing environment by immersing the AH-1Q fuselage in the icing cloud for 20 minutes. The TOW missile system was placed in STANDBY TOW before entering the cloud and the gunner acquired the CH-47C spray aircraft as a target. As the AH-1Q was stationed in the cloud, the TSU optical window glazed over with ice within seconds, making the window opaque and obscuring vision through the TSU. This condition existed until the aircraft landed and was deiced.

(4) During the time the AH-1Q fuselage was immersed in the icing cloud, the TOW missile system was in the STANDBY TOW mode. The TSU turret was periodically operated from the slaved position to full left and full right deflections. The turret position was monitored by the gunner, using external turret direction indicator. After nine minutes in the icing cloud and with approximately 3/8-inch ice accretion on the TSU turret direction indicator, the TSU turret failed to move when commanded by the gunner. The ice accreted on the TSU turret formed an ice weld between the stationary and movable components, immobilizing the TSU turret.

(5) The test aircraft was configured in the 8-TOW configuration. There were 8-TOW missile launch containers installed that had been blocked off at the nose end to simulate TOW missiles. The maximum local accumulation of ice on the launchers after 20 minutes in the icing cloud was 1-1/2 inches. The ice accretion on the blocked missile launch containers was 1/4 inch. Ice formed inside each launcher tube from the forward edge down to the blocked missile launch container. The thickness of ice inside the tube was 1/4 inch, except along the bottom of the tube, where it was 1/2 inch.

e. Vibration, Performance, and Handling Qualities - No vibration, performance or handling qualities were performed on the AH-1Q during the icing evaluation.

16. USAAEFA Project No. 81-15, Support of United Technologies Corp., Sikorsky Aircraft Division, Icing Certification effort of the S-76 Helicopter (Reference A-21, Appendix A).

a. The Sikorsky Aircraft Division is attempting to certify the S-76 helicopter to fly into a forecast icing environment. USAAEFA was directed to provide up to 20 hours of flight support for Sikorsky Aircraft to evaluate the

S-76 and associated anti-ice/deice systems in the artificial icing cloud provided by the Helicopter Icing Spray System.

b. The evaluation lasted from 2 March to 24 March, 1982. A total of 16.3 hours of HISS time with approximately 6.9 hours of actual artificial cloud time were flown. The testing was conducted in St. Paul, Minnesota. Twelve artificial and one natural icing test flights were conducted.

c. Sikorsky ferried the aircraft to St. Paul, maintained the aircraft, and operated the aircraft. They conducted their own test and evaluated their results. The USAAEFA provided HISS, chase, and photo support along with extensive discussions on how USAAEFA conducts icing evaluations. The USAAEFA also provided some training and standardization for the Sikorsky crew. Four flights (two for each Sikorsky pilot) were conducted behind the HISS with Army pilots at the controls of the S-76. After that training only Sikorksy employees were onboard the S-76.

d. Sikorsky deposited funding with the Army before testing commenced. This was to cover anticipated expenses. If the balance of the account fell below ten percent remaining, the Army project officer was to obtain more funding from Sikorksy prior to allowing additional testing.

e. A list of special instrumentation or equipment installed in the S-76 is not available.

f. Ice Protection Systems - The S-76 was equipped with an electrothermal main and tail rotor deice system. The windshield pitot-statics and engines were also protected. A detailed description of these items is not available.

g. Ice Accretion and Shedding Characteristics, Vibration Performance and Handling Qualities - Results are not available. All test results were kept by Sikorksy and not disseminated to the Army.

17. USAAEFA Project No. 80-10, Helicopter Icing Spray System (HISS) Support for Bell Helicopter Textron (BHT) Model 412 Helicopter (Reference A-22, Appendix A).

a. Bell Helicopter Textron (BHT) conducted testing to certify the Model 412 helicopter to fly into a forecast icing environment. USAAEFA was directed to provide flight support for BHT to evaluate the 412 and associated anti-ice/deice systems in the artificial icing cloud provided by the HISS.

b. Testing was performed by BHT personnel after a minimum number of orienta-tion/training flights were flown by Army and BHT personnel behind the HISS. Specific test conditions are not available as all data was retained by BHT.

c. Instrumentation and Cloud Measuring Equipment - The instrumentation and special equipment installed in the BHT is listed in Appendix C-13.

d. Ice Protection Systems -

(1) The main and tail rotor deicing kit is supplied by the B. F. Goodrich Company. The entire system has received FAA conformity.

(a) Four each, Main Rotor Blade Elements. These fully encapsulated etched foil elements are arranged in a special fatigue resistant configuration and are formulated from a high strength beryllium-cooper alloy that has survived extensive fatigue testing.

(b) One each, Power Transfer/Distributor Unit.

(c) One each, Helicopter Deicing System Controller. The controller provides the main rotor "on" and "off" times and receives control commands from the pilot control panel. When the presence of cloud icing is detected by the "Hot Rod" icing detector, the pilot energizes the system by setting the icing environment selector switch to "above T1" for outside air temperature (OAT) above 10°F. After the system is activated, all other functions are preset and operate automatically. The "above T1" setting provides a system "off" time of two minutes and "below T1" an "off" time of four minutes. The Auto-Integrated Rate Unit (IRU) and liquid water content (LWC) modes use LWC and OAT readings which program the controller. If, during the tests, additional "on" and "off" time capabilities are required, the test controller can provide manual adjustment of both parameters. The controller includes an automatic system shutdown feature if blade temperature exceeds a predetermined value. The pilot control panel includes an emergency override switch which will allow, at the pilot's discretion, continued use of the rotor deicing system until the helicopter is clear of the icing clouds.

(d) Four each, Blade Connector Assemblies.

(e) Four each, Wire Harness Assemblies.

(f) Two each, Tail Rotor Deicers. These deicers are rubber deicers containing etched foil elements that are externally bonded to the blades.

(2) The 30 KVA alternator kit was installed to provide aircraft power for the main and tail rotor deicing system.

(3) The heated windshield was installed for evaluation of its adequacy for flight into known icing conditions.

(4) A Teddington Hot Rod ice detector was installed on the pilot's door as a visual reference for ice detection by the pilot.

(5) The heated pitot and static source systems were used during all icing flights.

(6) The aircraft was instrumented to record various parameters. Data were recorded on an airborne Ampex tape recording unit using the normal flight test methods. Visual gauges were also provided for quick reference of the cyclic, collective and pedal positions. Processing of the analog signals was handled at the test site while digitizing of the tape was processed at the Flight Research Center. All instrumentation systems were calibrated where applicable with these records being on file at the Flight Research Center. B.F. Goodrich installed a droplet catcher while was used to measure and compute the mean volumetric diameter of the icing droplets. This catcher used a gelatin slide which was exposed to the airstream for a timed period. The slides were

then examined under a microscope, the droplets were measured and counted. From this information a mean volumetric diameter was computed for each flight.

(7) Cameras were to be located on the mast, forward fuselage, and tailboom. The mast camera was used to take pictures along any one of the main rotor blades on the upper surface. The forward fuselage camera was used to take pictures on the lower surface of a main rotor blade while the tailboom camera was to be aimed at the elevators. The cameras were 35mm's with autowinders mounted in underwater camera cases. At the start of the test, only two cameras were available, so a 16mm movie camera was used on the mast for the first flight. During this flight the movie camera jammed, so it was decided to move the tailboom camera to the mast since this was the more important location. The tailboom camera was never reinstalled. A heated lens was installed on the mast camera since this camera accreted a large amount of ice. The fuselage camera could not be actuated fast enough (shutter speed) to freeze the bottom side of the blade. The pictures from this camera were unacceptable. Later examination of this camera showed an actual shutter speed of 1/600th of a second instead of 1/1000th as indicated on the camera. The mast-mounted camera, along with pictures taken from the chase plane, provided excellent photographs; however, BHT was never able to obtain pictures of the lower surface of the blade using the fuselage-mounted camera.

e. Ice Accretion and Shedding Characteristics, Vibration, Performance and handling Qualities - No data is available on vibration, performance, handling qualities or ice accretion and shedding characteristics as this data was retained by BHT.

18. USAAEFA Project No 73-04-4, Part I, Artificial Icing Tests UH-1H Helicopter (Reference A-23, Appendix A).

a. Complaints from field users of Army helicopters to the Department of the Army resulted in concern about safe operational capabilities in an icing environment. This led to the design and fabrication of the HISS and its initial use for artificial icing tests beginning in September, 1973. The UH-1H heli-copter was scheduled to be first in the artificial icing sequence because it had already been exposed to limited icing tests and was not prohibited from flight in forecast light icing conditions. General test conditions for this evaluation are shown in Appendix B-14.

b. Instrumentation and Cloud Measurement Equipment -

(1) In addition to performance and handling qualities instrumentation, vibration accelerometers, a laboratory thermometer, and a sensitive altimeter (to determine engine inlet plenum chamber static pressure) were installed on the test aircraft. A video camera was mounted to monitor the engine inlet but had a marginal picture quality due to changing light conditions. A detailed list of instrumentation is included in Appendix C-14.

(2) Cloud parameter measurement equipment was limited to a Rosemount ice detector and a visual ice accretion probe both installed on the cabin roof. The visual probe was used for establishing immersion times based on predetermined amounts of ice accretion. The Rosemount was used to quantify icing rate and provided the pilot with immediate information about the rate of fuselage ice accretion; however, since outside air temperature influences the types of ice

accretions, it was felt that the inaccuracies in the ship's temperature gage (as high as 6°C) could adversely affect icing operations and was termed a shortcoming.

c. Ice Protection Systems -

(1) The UH-1H was equipped with the standard aircraft anti-ice/deice systems (engine deice, pitot heat, and windshield defrost), as well as the Arctic environment auxiliary exhaust heater system and engine air inlet filters. The engine air particle separator was removed from the aircraft in accordance with standard winter procedures. A special windshield alcohol anti-ice system was installed on the pilot's windshield wiper blade.

(2) The standard aircraft anti-ice/deice systems operated effectively, except the windshield defrost, which was not capable of preventing the windshield from completely icing over after 15 seconds of exposure to HISS light icing conditions. The resulting obscurations of forward and downward field-of-view were classed as a deficiency and a shortcoming, respectively, and led to a recommendation for effective windshield ice protection systems as a pre-requisite for UH-1H icing operations. The special alcohol anti-ice system kept the windshield free of ice during all of the tests; however, the windshield was badly scratched and gouged.

d. Ice Accretion and Shedding Characteristics -

(1) Fuselage ice accretions were compared with the FAA icing severity definitions (using a visual ice accretion probe) and found to essentially conform. The FM antenna ice accretions led to large amplitude oscillations which caused the antenna to strike the tail rotor. The tail rotor was not damaged; however, the antenna was significantly damaged and was removed for the remainder of the tests. Ice did not accrete on the inboard sections of the synchronized elevator, vertical stabilizer, or the tail rotor due to heat from the engine exhaust (an enhancing characteristic); however, for 1/4 inch accumulation of ice on the visual probe, 7/8 inch of ice was found on the main rotor blades. This led to the conclusion that the FAA icing severity definitions were not adequate for the rotor system and needed to be expanded.

(2) The main rotor exhibited symmetrical shedding in simulated light icing conditions at -4°C. Light icing at -9°C and all moderate icing encounters resulted in asymmetric sheds. Random shedding from the main rotor and fuselage struck the fuselage in flight. During landing, pieces of ice were flying as far as 300 feet, resulting in a WARNING being placed in the Operator's Manual.

e. Vibration - Several 1/rev vertical vibrations caused by asymmetric sheds were encountered during testing. The most severe vibrations occurred after 22 minutes at 0.25 gm/m$^3$ and -10°C. Vibration levels at the pilot station changed from 0.08 g before the shed to 0.20 g and at the main transmission from 0.15 g to 0.46 g. The pilots were unable to read the cockpit instruments and considered evacuating the aircraft. A descent was initiated and after seven minutes the vibrations subsided. After landing a structural inspection was conducted with no apparent damage being reported. It was felt that this shed was severe enough to recommend restricting the UH-1H from flight into known or forecast icing conditions.

f. Performance - There were no changes in aircraft performance associated with fuselage icing; however, torque rises could be associated with main rotor icing. It was found that a torque rise of six to nine pounds per square inch (psi) could be associated with 1/2" to 3/4" of ice on the leading edge of the main rotor blades (after landing). When torque rises reached or exceeded five psi (approximately 3/8" to 1/2" ice on leading edge), autorotative rpm could not be maintained.

g. Handling Qualities -

(1) Control positions in trimmed forward flight and static longitudinal stability were checked with main rotor ice accretions. No apparent changes to the handling qualities of the UH-1H could be documented.

(2) These tests were the first operational use of the HISS. Several problem areas were discovered during the course of testing. The CH-47 rotor downwash caused an increase of five to six psi in engine torque for the test aircraft. The lowest turbulence levels were found to be between 100 to 300 feet from the spray boom, thus establishing 150 feet as the test standoff distance. The spray cloud developed was five feet deep by 25 feet wide, and was not sufficient to completely envelop the test aircraft. It was also found that excessively large droplets were produced and that ice formed and was shed from the spray boom, creating a hazard.

19. USAAEFA Project No. 73-04-4, Part II, Artificial Icing Tests UH-1H Helicopter (Reference A-24, Apprndix A).

a. Artificial icing tests of the UH-1H in Alaska using the original HISS (configuration 1974), had revealed that a major deficiency was the obscuration of forward vision by the formation of ice on the windshields. To correct this deficiency, heated glass windshields were installed and tested. General test conditions for this evaluation are shown in Appendix B-15.

b. Instrumentation and Cloud Measurement Equipment - Instrumentation for this evaluation was limited to a heated total temperature system, in-flight and post flight photography to document windshield function, and a voice recorder for pilot comments. A visual ice accretion probe was used to measure the incremental accumulation of ice and determine the icing severity.

c. Ice Protection Systems -

(1) A glass windshield with a ten inches high by 34 inches wide heated portion was used as both a deice and an anti-ice system. When activated as a deice system, the windshield was capable of clearing a 1/8" layer of ice in 45 seconds. As an anti-ice system, it was completely effective in preventing windshield ice accretion.

(2) If the windshield was not activated prior to cloud entry (used as a deice system), the windshield was completely iced over after 15 seconds of exposure. After activation, the 10 inch by 34 inch deiced area allowed excellent forward field-of-view; however, ice on the remainder of the windshield still restricted upward and downward field-of-view.

d. Ice Accretion and Shedding Charateristics, Vibration, Performance and Handling Qualities - Not applicable to this test.

20. USAAEFA Project No. 74-31, Natural Icing Tests, UH-1H Helicopter (Reference A-25, Appendix A).

a. To validate the results of the artificial icing tests, natural icing tests of a modified UH-1H were conducted. General test conditions are shown in Appendix B-16.

b. Instrumentation and Cloud Measurement Equipment -

(1) A photopanel system was used to record performance and handling qualities parameters, and a magnetic tape system was used to record various vibration data. A differential pressure measuring gauge was used to measure the difference between ambient static pressure and engine inlet static pressure. A cassette tape recorder for pilot comments and a sensitive total temperature system were also installed. A detailed instrumentation list is included in Appendix C-15.

(2) Cloud parameter measurement equipment consisted of a visual ice accretion probe and a Rosemount ice detection and accretion rate system, both installed on the cabin roof. The visual probe was used as in previous tests to establish immersion times based on predetermined amounts of ice accretion. The Rosemount ice detector was used to correlate icing severity and also provided the pilot with immediate information about the rate of fuselage ice accretion (an enhancing characteristic).

c. Ice Protection Systems - The test aircraft was equipped with the standard aircraft anti-ice/deice systems plus electrically heated glass windshields. As in previous tests, the standard systems operated effectively except the windshield defrost which couldn't prevent ice formation on the upper three-fourths of the windshield. The electrically heated windshields were completely effective and were considered an enhancing characteristic.

d. Ice Accretion and Shedding Characteristics -

(1) Fuselage ice accretions were similar to those encountered in the artificial environment. Heat from the engine exhaust prevented ice from accumulating on the inboard portions of the synchronized elevator. FM antenna ice accretions resulted in large-amplitude oscillations which led to tail rotor strikes causing antenna damage. The left engine air inlet filters accumulated significant amounts of ice; however, no adverse engine effects could be determined.

(2) The ice shedding characteristics correlated very closely with those observed during previous artificial testing (Project No. 73-04-4, part I). No asymmetric main rotor sheds occurred when temperatures were at or above -5.5°C (the coldest temperature encountered during this evaluation). During landing and shutdown operations, ice was shed in all directions by the main rotor blades as noted during artificial tests.

e. Vibrations - Vibration levels remained normal throughout all testing except one flight, during which a mild low frequency lateral vibration occurred periodically.

f. Performance - Increased power required was associated with main rotor ice accretion. Exposure to moderate icing conditions led to a torque rise of

5.5 psi after 3/4 inch of ice had accreted on the visual probe. Autorotational rotor speed could not be maintained within operational limits during the aforementioned immersion, and led to a recommendation to prohibit flight into known icing conditions.

g. Handling Qualities - Pilot comments and recorded data showed no apparent changes to the handling qualities of UH-1H with ice accumulation.

21. USAAEFA Project No. 74-13, Artificial Icing Tests, Lockheed Advanced Ice Protection System Instilled on a UH-1H Helicopter (Reference A-26, Appendix A).

a. Artificial icing tests were conducted in conjunction with Lockheed-California Company to determine the conceptual feasibility of the electrothermal rotor blade ice protection system. General test conditions are shown in Appendix B-17.

b. Instrumentation and Cloud Measurement Equipment -

(1) Since this evaluation was primarily a research and development effort, an extensive instrumentation package was installed in the test aircraft. In addition to performance and handling qualities instrumentation, structural loads, vibrations, temperature, and voltage parameters were also monitored. A 16 mm rotor hub mounted camera was installed on top of the main rotor slip ring housing canister. This electrically heated camera assembly was used to provide in-flight photographic coverage of main rotor blade ice accumulation and shedding. A detailed list of instrumentation is included in Appendix C-16.

(2) Two ice detection systems, manufactured by Rosemount Engineering Company and Leigh Instruments Ltd., and a visual ice accretion probe were used to measure rate of accretion and the incremented accumulation of ice. Both ice detectors experienced problems during these tests. The Rosemount probe continually accumulated significant quantities of ice when LWC was greater than 0.25 gm/m$^3$ and temperatures were colder than -5.0°C, making it unusable. The Leigh ice detection system either failed to operate properly or provided erratic, random readings. Since attempts to repair the Leigh system were unsuccessful, no usable information was provided for operation of the ice protection system in either the automatic or semiautomatic modes.

c. Ice Protection Systems -

(1) Nonstandard anti-ice/deice equipment installed on the UH-1H for the evaluation included heated glass windshields for both the pilot and copilot, modified main and tail rotor blades incorporating full span leading edge electrothermal deicer heater elements, modified stabilizer bar and tip weights incorporating full span electrothermal anti-ice blankets, and an extensively modified ship's electrical system.

(2) The operation of the heated windshields provided excellent forward field-of-view at all times. While the concept of operation of the ice protection system was determined to be feasible, it was felt that further testing to optimize the system and investigate effects of runback and ice accumulation on unprotected areas was necessary. In addition, the number and nature of failures of the system would have precluded safe flight in natural icing conditions and the poor reliability of the system was poor.

d. Ice Accretion and Shedding Characteristics -

(1) Specific tests to determine the effects of prolonged fuselage immersion in the icing cloud were not conducted; however, due to turbulence and the inability to maintain vertical position, intermittent fuselage immersions occurred. Ice was noted on the vertical fin, right side of the fuselage, and on the right engine inlet barrier filter. As in previous tests, large amplitude oscillations of the FM antenna were observed. The antenna had been canted 15° from the vertical; although a tail rotor strike did not occur, it was felt that the amplitude was sufficient to damage the antenna, and it was removed for subsequent flights.

(2) As observed in previous testing, heat from the engine exhaust prevented ice accretion on the tail rotor blades. There appeared to be a direct correlation between temperature and the amount of spanwise ice accretion. Extensive ice accumulations were observed on the unprotected portions of the main rotor. Due to limited cloud immersion times (that which would allow 1/4 inch ice buildup at 40 percent blade span), no asymmetric sheds occurred and no runback was observed on the main rotor blades. Intermittent incomplete sheds of the inboard sections of the main rotor occurred, necessitating changes in power density and ON time.

e. Vibration - No significant increases in vibration levels over normal levels were observed during this evaluation.

f. Flight Loads - Structural loads on critical components were monitored in real time throughout the evaluation. While the loads increased during cloud immersions, they were well below the endurance limits as defined by Bell Helicopter Co. for those components.

22. USAAEFA Project No. 75-26, Lockheed Advanced Ice Protection System Test (Reference A-27, Appendix A).

a. In a continuation of the effort to evaluate the feasibility, and optimize the Lockheed Advanced Ice Protection System, this evaluation was conducted at the National Research Council's spray rig in Ottawa. General test conditions are listed in Appendix B-18.

b. Cloud Measurement Equipment -

(1) Three separate ice detection systems were installed on the test aircraft: a Rosemount ice detection and accretion rate system; a Leigh ice detection system; and a Normalair-Garrett ice detection system. Due to the variable nature of the spray cloud under the helicopter rotor disc, no prolonged simultaneous or continuous immersion of the detectors was possible, precluding comparison of the systems.

(2) Nonstandard anti-ice/deice equipment installed on the UH-1H for the evaluation included heated glass windshields for both pilot and copilot, modified main and tail rotor blades incorporating full span leading edge electrothermal deicer heater elements, modified stabilizer bar and tip weights incorporating full span electrothermal anti-ice blankets, and an extensively modified ship's electrical system.

(3) As in previous testing, the operation of the heated windshields provided excellent forward field-of-view at all times. The stabilizer bar and tip weights had insignificant ice accumulations on unheated portions and there was some evidence of runback on outboard portions; however, the operation of the system was still considered satisfactory. Operation of the main rotor deice system was satisfactory except for some incomplete shedding of inboard sections and two system failures due to manufacturing defects.

c. Ice Accretion and Shedding Characteristics -

(1) During the spray rig testing, the engine inlet barrier screens continually iced over. On several occasions, testing was terminated prematurely because engine inlet delta pressure reached predetermined limits. This phenomenon had not been observed in prior evaluations.

(2) A standard hot metal/exhaust plume infrared suppressor was installed to evaluate the effect on the tail rotor. No detectable difference in the icing characteristics of the tail rotor was noted with the IR suppressor installed or removed. The tail rotor accreted a maximum of 0.20 inch ice and ice shedding was satisfactorily induced. The main rotor had maximum chordwise ice coverage of 1.5 inches on the top and four inches on the bottom surfaces. Runback occurred on both the top and bottom of the main rotor blades to a maximum thickness of 0.25 inch. This amount of runback was considered insignificant since no discernible change in performance could be detected while hovering in the spray rig.

d. Vibation, Performance and Handling Qualities - Not evaluated during this test.

23. USAAEFA Project No. 77-30, Artificial Icing Test, Ice Phobic Coating on UH-1H Helicopter Rotor Blades (Reference A-28, Appendix A).

a. For many years, the Army has been attempting to find a lightweight, inexpensive substance that can be easily applied to aerodynamic surfaces which would either prevent the formation of ice or reduce the surface adhesion force to the extent that aerodynamic and/or dynamic forces would remove the ice. Two such ice phobic coatings (Dow Corning E2460-40-1 and General Electric G697) were tested on UH-1H rotor blades in the HISS cloud at the general conditions listed in Appendix B-19.

b. Instrumentation and Cloud Measurement Equipment - Calibrated indicators were installed in place of and in addition to normal cockpit indicators to monitor basic aircraft performance parameters. In addition, an FM data recording system was used to record collective control position, engine torque pressure and triaxial vibrations at three positions. A visual ice accretion probe was used by the pilot as a visual cue of the ice buildup on the helicopter. A detailed instrumentation list is included in Appendix C-17.

c. Ice Protection Systems - An electrically heated glass windshield with an isopropyl alcohol spray system attached to the lower edge was used as an anti-ice system for safety reasons. Two different ice phobic compounds, Dow Corning E2460-4-1 (redesignated E2978-46) and GE G697, were evaluated for useful life and ice accretion and shedding characteristics. Application techniques used for the G697 were a spray technique and a wipe technique, while the E2460

was limited to the spray technique. The wipe technique was considered satisfactory for applying the G697 compound; however, because of excessive application time and critical ambient light conditions, the spray technique was unsatisfactory. During the tests, it was determined that the E2460 substance caused personnel discomfort (eye and throat irritation) and required the use of clear unvented protective eye goggles and a vapor-proof breathing mask to prevent these irritations. The erosion and flow characteristics of the E2460 substance were acceptable while those of the C697 were unsatisfactory.

d. Ice Accretion and Shedding Characteristics -

(1) Unprotected main rotor blade ice accretion and shedding characteristics were evaluated at -5 and -10°C and an LWC of 0.5 gm/m$^3$. The ice accreted on the main rotor blades at -5°C required increased power for level flight, adversely affected autorotational performance, and shed randomly. The same was true for ice accreted at -10°C with the addition of severe lateral 1/rev vibrations and damaged aircraft components. It was felt that these findings agreed with previous icing test data, and these data were subsequently used as a baseline for evaluating ice phobic coated main rotor blade characteristics.

(2) The E2460 substance demonstrated an increased rotor blade ice shedding capability through -10°C and LWC to 0.5 gm/m$^3$. It did not provide adequate protection for a significant period of time at -15C.

(3) The G697 compound demonstrated a slightly increased but inadequate rotor blade ice shedding capability at -5°C, and was also inadequate at -10°C.

e. Vibration - Asymmetric main rotor blade ice sheds occurred throughout the test with clean, as well as with coated, blades. The most severe shed with clean blades occurred at -10°C and LWC of 0.50 gm/m$^3$ resulting in a 0.08g 1/rev lateral vibration (VRS 8) after 20 minutes of cloud immersion. The most severe shed with coated blades (E2460 substance) occurred at -10°C and LWC of 0.50 gm/m$^3$ resulting in a 0.12g 1/rev lateral vibration (VRS 9) after 40.5 minutes of cloud immersion.

f. Performance - As in previous tests, ice accretion on the main rotor blades led to torque rises and an accompanying degradation of autorotational performance. Highest torque rise with clean blades was 8.2 psi after 28 minutes of immersion at -5°C and LWC of 0.5 gm/m$^3$. Highest torque rise with coated blades (E2460) occurred after 13 minutes of immersion at -15°C and LWC of 0.25 gm/m$^3$ and resulted in termination of the flight.

24. USAAEFA Projects Nos. 78-21 and 78-21-2, Artificial and Natural Icing Tests Qualification of UH-1H Kit A Aircraft; and Microphysical Properties of Artificial and Their Effects on UH-1H Helicopter Icing (References 29 and 30, Appendix A).

a. As part of a continuing effort to develop an all-weather capability in the U.S. Army fleet, a partial ice protection system (Kit A) was developed for the UH-1. It was anticipated that while the UH-1H equipped with Kit A would be severely limited due to the lack of a rotor blade deicing system, an envelope could be developed which would provide a limited capability to operate in light icing conditions. This evaluation was a two phase effort designed to satisfy various research and development objectives of the Federal Aviation

Administration (FAA) and the Applied Technology Laboratories (ATL), as well as qualify the Kit equipped aircraft for intentional flight into icing conditions. General test conditions for this evaluation are shown in Appendix B-20.

b. Instrumentation and Cloud Measurement Equipment -

(1) Sensitive cockpit gages and an oscillograph recording system were used to monitor performance, handling qualities, main and tail rotor loads, and main and tail rotor temperature parameters. A 16 mm movie camera was installed on top of the main rotor slip ring housing canister. This camera provided in-flight color photographic coverage of main rotor blade ice accumulation and shedding wa valuable tool. A detailed list of instrumentation and special equipment is included in Appendix C-18.

(2) To acquire research and development related ing test data, numerous cloud parameter measurement systems were used. A Cambridge dew point hygrometer and sensitive Rosemount OAT display were used to calculate relative humidity. Three separate ice detectors and icing severity level indicators were installed on the test aircraft. The Rosemount, Leigh Mk X, and Leigh Mk XII detectors all gave sporadic and unreliable readings during artificial testing; however, in natural icing, all three gave stable indications which compared favorably with each other, as well as with the other liquid water content (LWC) devices. An Integrating Rate Unit (IRU) was used to help quantify the occurrence of asymmetric sheds, and a visual ice accretion probe gave the copilot a visual cue to ice buildup on the helicopter.

(3) The test objectives involving artificial and natural icing cloud parameter data (LWC and droplet size distribution) were obtained from an axially scattering probe (ASP) and a cloud particle spectrometer (CPS) installed on the test aircraft by Meteorology Research Incorporated (MRI). The ASP sizes particles by measuring the amount of light scattered into the collecting optics aperture during particle interaction through a focused laser beam. In the CPS, particles are sized using a linear array of photodiodes to sense the shadowing of array elements by particles passing through its field of view.

c. Ice Protection Systems -

(1) The test aircraft was equipped with the standard aircraft anti-ice/deice systems (engine deice, pitot heat, and windshield defrost), Kit A partial ice protection system, and the Lockheed Advanced Ice Protection System. The Kit A system included: 30 KVA three-phase alternator; 200 amp AC to DC converter; electrical system control and distribution changes; heated glass windshields and individual controllers; Rosemount ice detector and icing severity level indicator; and a Rosemount OAT sensor and control mounted display. The Lockheed Advanced Ice Protection System had been developed by Lockheed under a contract from ATL and had been tested by USAAEFA during the 1975 and 1976 icing seasons. The Lockheed system was primarily used for safety purposes (to remove residual ice from the blades after an asymmetric shed); however, operation was closely monitored to provide data concerning the function of the chordwise heater blankets.

(2) The AC electrical system functioned properly throughout the test program (more than 90 flight hours) except for a minor leak at the Garlock seal on the 30 KVA alternator drive shaft. The Rosemount OAT probe functioned

properly during both natural and artificial testing; however, the digital display exhibited poor readability. Extended exposure to the HISS environment resulted in total icing of the electrothermally heated windshields at temperatures colder than -10°C. Operation in natural icing conditions (within the limits of the conditions encountered) presented no problem to the pilot's field-of-view with the Kit A windshield or the standard windshield if the defog heater was activated prior to cloud entry. The conclusion was reached that Kit A did not increase the operational capability of the UH-1 aircraft equipped with glass windshields in the icing environment.

(3) The blade deice system reliability was acceptable with two broken wires causing the only malfunctions in more than 30 cycles. On two occasions at -20°C and colder, the heater elements failed to remove accumulated ice from the blades indicating that the heater ON schedule provided insufficient heat to overcome the surface adhesion of the ice at temperatures of -20°C and colder.

d. Ice Accretion and Shedding Characteristics -

(1) Ice accretion characteristics were observed and documented during all artificial and natural testing. The ice accumulations under both natural and artificial conditions were similar with the major differences occurring in ice texture and thickness. HISS formations were larger and of a more granular texture than those produced by natural conditions.

(2) The forward fuselage and all protrusions that provided a stagnation point had increased accretion rates because of the impacting of 1 size droplets. The battery vent located on the nose of the aircraft accu lated ice readily which resulted in partial blockage. The sides of the fuselage showed little tendency to accumulate ice with maximum accretions less than 1/16 inch. The maximum accumulation of ice on the flight controls occurred on the stationary swashplate and approached 1 1/2 inches. The aft fuselage, tail boom, and tail rotor exhibited negligible ice accretion. The right horizontal stabilizer consistently accreted larger amounts of ice than the left due to downwash which caused greater impingement of the exhaust gases and warmer temperatures on the left stabilizer.

(3) Due to the h rotational velocity, it was anticipated that the main rotor would be the iting component during icing flight; however, under 54 percent of the conditions tested, the main rotor exhibited a symmetric shed tendency which did not adversely affect the aircraft characteristics. On six occasions of 13 test runs, main rotor asymmetric shed occurred which increased the airframe vibration level from one to approximately four on the VRS. The data from these flights produced poor repeatability and showed little correlation between the variables of LWC, OAT, IRU counts, and time to the shed point.

e. Performance -

(1) In artificial conditions, the torque rise was masked by the fuel burn-off and the power variations required to maintain positioning in the HISS plume. The most severe torque rises encountered during natural icing conditions were 5.4 and 4. psi at OAT of -12°C, LWC of 0.1 gm/m$^3$ and OAT of -6°C, LWC of 0.21 gm/m$^3$, respectively.

(2) The maximum decrease in autorotational rpm during the testing was 20 rpm, leaving the autorotational rpm well within the recommended operational

range. It was also noted that entry into autorotation in many cases resulted in a partial or total shed of the accumulated ice.

f. Handling Qualities - The handling qualities of the helicopter were qualitatively evaluated throughout the test program with no apparent variations noted.

g. Hiss Capabilities and Limitations -

(1) Using the laser nephelometers (ASP and CPS) installed on the test aircraft, much of the test effort was directed at evaluating the microphysical properties of the natural and artificial icing environments. These results were then to be used to help determine the adequacy of the artificial cloud as a representation of natural conditions.

(2) The effects of relative humidity variations were evidenced by plume density, formation of a visible wake from the HISS, and variations in ice accretion on the test aircraft. A marked increase in the number of small droplets (<15 microns) was noted at high relative humidity.

(3) Standoff distance was evaluated at 150, 200, and 250 feet. The standoff distance did not materially affect the cloud composition; however, the concentration of 10 to 15 μm droplets was reduced at 250 feet when compared to 150 ft.

(4) Water flow rate effects produced two readily evident results. The concentration of droplets less then 50 μm was relatively unchanged and the concentration of larger droplets was increased by as much as two orders of magnitude at higher flow rates. These results indicated that the nozzles used in this HISS configuration had a limited capacity to produce small droplets and that this capacity was saturated at higher flow rates of interest.

(5) Due to gravitational sorting effects, the majority of the large droplets were encountered in the lower third of the spray plume. These plume variations are greatly magnified with respect to LWC. In fact, the LWC calculated from the HISS flow rate could be exceeded by a factor of five at some points in the plume. These LWC variations result in localized areas of the aircraft experiencing different icing environments, reducing the validity of the simulation.

(6) The nonprecipitating natural stratus cloud produces a characteristic peak in droplet concentration at approximately 15 m and then trails off rapidly to a maximum droplet size of approximately 90 μm. The HISS plume reached an initial peak concentration an order of magnitude higher at a droplet size of approximately 60 μm and the concentration remained relatively constant to 200 μm before trailing off with a maximum droplet size of approximately 300 μm. This established that the HISS plume was not a valid representation of the nonprecipitating natural cloud.

25. USAAEFA Project No. 79-02, UH-1H Ice Phobic Coatings and Calibration of Modified HISS (Reference A-31, Appendix A).

a. Results of prior tests indicated that the original HISS configuration did not produce a cloud representative of the natural environment; therefore, the HISS was modified to configuration 1980 (Table 1) to provide a more suitable

simulation. Initial testing during this evaluation was conducted to evaluate and document the HISS. The ATL had investigated ice phobic coatings as an interim solution to the helicopter rotor blade icing problem. This evaluation was conducted to further evaluate the effectiveness of ice phobic coatings and to obtain icing flight data for ATL and FAA research and development objectives. General test conditions are shown in Appendix B-21.

b. <u>Instrumentation and Cloud Measurement Equipment</u> -

(1) Sensitive cockpit gages and/or a magnetic tape recording system were used to monitor performance, handling qualities, main and tail rotor pitch link loads, and vibration parameters. A 16mm movie camera was installed on top of the main rotor slip ring housing canister. This camera was intended to provide in-flight color photographic coverage of main rotor blade ice accumulation and shedding; however, because of numerous malfunctions, little documentation was obtained. A detailed list of instrumentation and special equipment is included in Appendix C-19.

(2) To acquire research and development related icing test data, numerous cloud parameter measurement systems were used. A Cambridge dew point hygrometer and sensitive Rosemount OAT display were used to calculate relative humidity. Three separate ice detectors and icing severity level indicators, Rosemount, Leigh Mk 10, and Leigh Mk 12, were installed on the test aircraft. The accuracy and operational capability of these ice detectors were evaluated by comparing time histories of natural icing encounters with LWC calculated from the MRI laser nephelometer droplet distribution data. Reasonably good agreement between the individual sensors was obtained when allowance was made for the different physical locations on the airframe. An IRU was evaluated as an indicator designed to provide an operational pilot cues as aircraft limits are approached. Although the IRU appeared to be working properly, there was poor correlation between the occurrence of an asymmetric shed and IRU counts. A visual ice accretion probe gave the pilot a visual cue of the amount and rate of ice buildup; however, no correlation existed between ice buildup on the probe, LWC, IRU indications, or asymmetric sheds.

(3) The test objectives involving artificial and natural icing cloud parameter data (LWC and droplet size distribution) were obtained from an ASP and CPS installed on the test aircraft by MRI.

c. <u>Ice Protection Systems</u> -

(1) The test aircraft was equipped with the standard aircraft anti-ice/deice systems and the ice protection system (IPS) for safety purposes. The IPS, a combination of Kit A and the Lockheed Advanced Ice Protection System, provided protection for the main rotor blades, stabilizer bar/tip weights, pilot/copilot windshields, and tail rotor blades (not operational for this test).

(2) General Electric G661 ice phobic compound was evaluated for useful life and ice accretion and shedding characteristics. Several application techniques were evaluated; a wipe-on technique using a paint applicator, a brush-on technique using a paint brush, and a roll-on technique using a nine inch nylon paint roller. The roll-on technique was found to be the cleanest, quickest, and easiest method of applying a uniform coating. To prevent

personnel discomfort, rubber gloves, clear unvented eye goggles, and an organic vapor respirator were worn by application personnel. It was felt that since the application of an ice phobic compound is intended as an expedient means to fly in icing conditions, the need for maintenance stands on ladders, protective personnel equipment, and the appreciable man-hours required for preparation and application significantly degraded the practicality of G661. In addition, the erosion and flow characteristics of the G661 were poor on the leading edge of the main and tail rotor blades.

d. Ice Accretion and Shedding Characteristics - No ice was noted on the tail rotor blades. The limited hub camera film available showed 1/4 to 1/2 inch thick ice accreted on the leading edge of the main rotor blade. The maximum torque rise encountered was three psi (after correcting for fuel burnoff). No predetermined test limits were reached during testing; however, nine minor asymmetric sheds occurred. Because uncoated blade testing was not accomplished during these tests and insufficient data were available from previous tests, it was felt that it was not possible to determine any changes in operational icing capability attributable to G661.

e. Vibrations - The lateral vibrations resulting from the asymmetric sheds were slight to moderate (VRS 3 to 4), with a maximum amplitude of 0.19g at a frequency of 5.4 hertz. All sheds were of short duration (approximately 15 seconds) and caused minimal concern to the aircrew. Less than 50 percent of the natural icing encounters produced an asymmetric shed, providing little repeatable quantitative data.

26. USAAEFA Project No. 80-13, HISS Calibration, Ice Phobics and R&D Evaluations (Reference A-32, Appendix A).

a. The ATL required additional artificial testing to quantify the effects of ice phobic coatings on main and tail rotor blades. Additional natural icing tests were required to further explore the capability of the UH-1H to operate in icing conditions. These tests were also intended to be used by the FAA to help establish icing certification and operational requirements for commercial helicopters operating with minimum ice protection systems capability. And finally, as a result of modifications to the HISS (configuration 1981), a spray cloud recalibration was required. General test conditions for this evaluation are shown in Appendix B-22.

b. Instrumentation and Cloud Measurement Equipment -

(1) Sensitive cockpit gages and a magnetic tape recording system were used to monitor performance, handling qualities, main and tail rotor pitch link loads, and vibration parameters. A 16mm stop action camera was mounted on the inside of the right hinged panel door. A strobe light was incorporated in the design to allow photographing a single main rotor blade throughout the flight. Because of numerous malfunctions, no usable data was obtained from this camera. A detailed list of instrumentation and special equipment is included in Appendix C-20.

(2) To acquire research and development related icing test data, numerous cloud measurement systems were used. A Cambridge dew point hygrometer and sensitive Rosemount OAT display were used to calculate relative humidity. Three separate ice detectors, Rosemount, Leigh Mk 10, and Leigh Mk 12, were installed on the test aircraft. Two IRU devices were installed to attempt to

provide an operational pilot cue as aircraft limits were approached. A visual ice accretion probe was mounted on the test aircraft to give the copilot a visual cue of ice buildup on the helicopter.

(3) The test objectives involving artificial and natural icing cloud parameter data (LWC and droplet size distribution) were obtained from the ASP and CPS installed on the test aircraft by MRI.

c. Ice Protection Systems -

(1) The test aircraft was equipped with the standard aircraft anti-ice/deice systems and the IPS for safety purposes.

(2) General Electric G661 ice phobic compound was evaluated for capability of the UH-1H to operate in icing conditions. Results of flights in artificial icing with the coating applied to the blades were compared to the results of flights at the same target conditions with clean blades. Based on these comparisons, G661 did not significantly affect the capability of the UH-1H to fly in icing conditions and it was recommended that no further testing of this compound be conducted.

d. Ice Accretion and Shedding Characteristics and Vibration -

(1) The test helicopter remained in the HISS cloud for approximately one hour or until predetermined limits (excessive vibration from asymmetric ice shed or 5 psi torque rise) were reached. Comparison of times to the first moderate vibration showed: the coated blades were inferior for five test conditions, superior for two, and the same as uncoated blades at one. In the comparison of times until the first severe shed, the coated blades were inferior for four test conditions and superior for three.

(2) Based on the uncoated blades' flight results, prolonged flight (over 10-15 minutes) into light icing was not recommended and flight into moderate or higher intensity icing was recommended to be prohibited. This prohibition was based on the moderate to severe vibration encountered as a result of asymmetric ice sheds from the main rotor; increases in power required and degradation of autorotative rpm due to ice accretion; and increased maintenance requirements because of ice striking the helicopter during an ice shed.

e. Performance - Comparison of the increases in power required and autorotative rpm degradation showed that coated blades were superior to clean blades. Power increases of greater than five psi torque were experienced twice with coated blades and seven times with clean blades. Autorotative rpm degradation greater than 15 rotor rpm was experienced once with coated blades and five times with clean blades.

27. USAAEFA Project No. 81-11, JUH-1H Pneumatic Boot Deicing Systems Flight Test Evaluation (Reference A-33, Appendix A).

a. Pneumatic deicer boots have seen extensive application on fixed wing aircraft. Numerous material problems, however, have prevented their use on helicopter rotors. The concept was revived by development of an erosion resistant polyurethane elastomer (trade name ESTANE ) by the BF Goodrich (BFG) Company. In 1979, the National Aeronautics and Space Administration's (NASA) Lewis Research Center in cooperation with BFG conducted limited wind tunnel

icing tests to evaluate the feasibility of pneumatic boot deicing concepts for helicopter rotor systems as reported by NASA/Lewis in 1980. To flight test the concept, NASA's/Ames Research Center requested the assistance of the U.S. Army AVSCOM.

b. BFG manufactured the prototype ESTANE pneumatic boots and installed them on a set of government-furnished UH-1H main rotor blades provided by NASA/Ames. Bell Helicopter Textron (BHT), under a NASA contract, instrumented two main rotor blades, main rotor hub, mast, pitch change link, and the three main rotor control actuator extension tubes for in-flight measurement of structural loads. BHT also designed and built an instrumentation and pneumatic slip ring assembly (incorporating the BFG furnished rotating union) which was installed on the test helicopter at USAAEFA prior to testing.

c. The objectives of this evaluation were to determine an operational flight envelope and conduct feasibility testing of the Pneumatic Boot Deicing System (PBDS) conception on a JUH-1H in both dry air and artificial icing conditions.

d. The test JUH-1H is a thirteen-place single engine helicopter using a single two-bladed teetering main rotor and a two-bladed pusher tail rotor. The maximum gross weight of the helicopter is 9500 pounds. Power is provided by a Lycoming T53-L-13 free turbine engine rated at 1400 shaft horsepower (shp); however, the helicopter is limited by the transmission to 1100 SHP. A more complete description may be found in the Operator's Manual. The test JUH-1H helicopter, USA S/N 70-16318, was a standard production helicopter manufactured by BHT and has been modified to incorporate a partial ice protection system (Kit A).

e. A prototype ESTANE deicer boot was applied to the leading edge of a standard UH-1H rotor blade. The deicer boot is designed to remove accumulated ice through pneumatic expansion (inflation) of chordwise and spanwise tubes. The PBDS also consists of a modified mast, electrical and pneumatic slip rings, associated controllers, electrical components, and air supply components for providing engine bleed air to the PBDS. Customer bleed air from the engine is routed to the deicers in a single inflation activation cycle. A normal activation cycle consists of inflation of the deicer boots for approximately two seconds, followed by subsequent deflation.

f. PBDS testing was conducted in three phases. The flight loads survey (Phase I) and performance and handling qualities testing (Phase II) were conducted at Edwards Air Force Base (EAFB), California, during the period of 16 November 1981 through 30 Oct 1982. Artificial icing tests (Phase III) were conducted between 4 January and 25 February, 1983, at Ottawa, Ontario, Canada. A total of 41 test flights were conducted during which 39.6 hours were flown. Where possible, flight test data were compared with data obtained from previous flight testing of the UH-1H. General test conditions for the evaluation are shown on Appendix B-23, instrumentation and special equipment is shown in Appendix C-21.

g. The evaluation of the PBDS consisted of three phases. Phase I was a ground and in-flight structural loads survey which established an operational envelope up to 100 knots calibrated airspeed (KCAS) in forward flight (deflated configuration) and 20 knots true airspeed (KTAS) in sideward and rearward

flight. Monitored structural loads demonstrated that the test helicopter with the PBDS installed may be safely flown through the established envelope. Six problems with the PBDS consisted of three phases. Phase I was ground and in-flight structural loads survey which established an operational envelope up to 100 knots calibrated airspeed (KCAS) in forward flight (deflated configuration) and 20 knots true airspeed (KTAS) in sideward and rearward flight. Monitored structural loads demonstrated that the test helicopter with the PBDS installed may be safely flown through the established envelope. Six problems with the PBDS were discovered during this phase, three of which were subsequently corrected by BFG. Phase II was a limited aircraft performance and handling qualities evaluation. The installation of the PBDS (deflated configuration) adversely affected the hover and level flight performance of the UH-1H with large increases in power required for flight. Handling qualities were not affected except with activation of the pneumatic deicer resulting in a right aircraft yaw. Phase III involved artificial icing tests in the National Research Council of Canada (NRC) icing spray rig. These tests demonstrated that the PBDS removed ice from the main rotor blades. Deicer material erosion and material failures were documented during all test phases.

h. Loads survey tests were conducted to establish a limited flight envelope for the UH-1H helicopter with the PBDS installed. While a normal PBDS activation cycle is transient and consists of a single deicer boot inflation immediately followed by deflation, for test purposes three sustained configurations were used: (1) deflated, representing the pneumatically expanded boot condition (normally of short duration) reached just after PBDS activation, and (3) vented, representing a failure mode caused by loss of bleed air allowing the boots to partially inflate. There were six PBDS problem areas found during Phase I: (1) excessive pneumatic boot deflation time during blade rotation (2) debonding of the pneumatic boot from the main rotor blade (3) self-activation of the PBDS timer (4) rupture (blowout) of the pneumatic boot during the inflation cycle (5) pneumatic deicer boot erosion and (6) reduction of pressure delivered to the pneumatic deicer boot through the heat soaked ejector control valve. All the problem areas except erosion resistance were improved or corrected during Phase I testing.

i. Ground tests were conducted at a 9,500 pound gross weight with the aircraft secured by a clevis to a tie-down anchor. Rotor and pitch change link loads were monitored for each boot condition during start and run up to ground idle and 294 and 324 rotor revolutions per minute (rpm). All loads monitored during the ground tests remained below endurance limits. Dynamic system/engine compatibility tests were done for 294 and 324 rotor rpm at three power settings (minimum, mid range and maximum) and no unusual dynamic response was noted throughout these tests. During the ground runs, an activation cycle of the PBDS at flat pitch resulted in an engine torque increase of three pounds per square inch (PSI) over the baseline 13 PSI required to maintain constant rotor speed. The deicer deflation time of 12 to 14 minutes was identified as a problem area and was decreased to 40 to 50 seconds by BFG after three modifications to the internal design of the pneumatic deicer boot which allowed progression to in-flight testing. Excessive pneumatic deicer deflation of 40 to 50 seconds remains a problem area. Temperatures of PBDS components during ground tests were monitored at selected locations by heat sensitive tape and thermocouples to determine if temperatures created by the customer bleed air were in excess of component's qualification values. Heat sensitive tape placed at the pressure inlet of the PBDS ejector flow control valve recorded a value of 160°F after

system operation at high aircraft power settings (above 40 PSI torque). Initial BFG high temperature environmental testing qualified the ejector valve to 160°F. The PBDS ejector flow control valve capability to pressurize the pneumatic deicer to 25 PSI decreased to as low as 16 PSI after the valve heat soaked during normal deicer operation. The inability of the ejector flow control valve to pressurize the pneumatic deicer to the BFG determined nominal pressure of 25 PSI was identified as a problem area. The ejector control valve was returned to BFG and was environmentally retested to 210°F in accordance with the experimental airworthiness release requirement to test to a temperature of 50°F greater than the maximum temperature recorded. Modification of the ejector control valve resulted in a higher deicer pressurization value of 22 PSI after the ejector control valve heat soaked. Reduction of system pressure after the ejector control valve heat soaks remains a problem area. Further modification of the ejector control valve to achieve the nominal system pressure of 25 PSI after heat soak should be accomplished prior to operational testing.

j. In-flight structural tests were conducted during hover, low airspeed, and forward flight at an 8000 pound takeoff gross weight and rotor speed of 324 rpm. Hover and low airspeed tests to 40 KTAS forward and 20 KTAS sideward and rearward were conducted in-ground effect (IGE) at all three deicer boot configurations (inflated, deflated and vented). The only monitored load which exceeded endurance limits during the in-flight structural test was the main rotor pitch link axial load. This load exceeded the structural endurance limit by 20 percent during activation of the PBDS in a 30° right coordinated turn and was not considered critical. During hover and low airspeed structural tests, the outboard, leading edge area (beyond blade station 240) of the pneumatic deicer exhibited erosion and small punctures of the ESTANE material. While undergoing the PBDS operational check after installation of the modified ejector control valve, one pneumatic deicer boot ruptured (blow out). This created a slight rotor vibration with loss of system vacuum during deflation. Rupture of the pneumatic deicer was recognized as a problem area.

k. Performance -

(1) Hover, level flight, and autorotational descent performance testing were conducted at Edwards Air Force Base, California (2302 foot elevation). Performance data were obtained with the PBDS in the deflated, vented and inflated configurations.

(2) Hover performance with deicer boots in the deflated, inflated, and vented configurations was evaluated using the tethered hover technique at a five foot skid height in winds of less than three knots. In dimensional terms, the performance penalties caused by the PBDS on a UH-1H at 9000 pounds on a standard day at sea level would be 100 shp deflated, 230 shp vented, and 370 shp inflated These values would correspond to power required increases of 11, 25, and 41 percent, respectively.

(3) The level flight performance of the test UH-1H with the PBDS installed was evaluated during trimmed ball-centered level flight at a thrust coefficient ($C_T$) of 0.0036 in the deflated and vented configurations using the constant gross weight to density ratio method. The PBDS was activated during steady state level flight at several airspeeds to evaluate the effect on the performance of the helicopter. At 90 KCAS, approximately 170 additional shp over standard UH-1H blades is required with PBDS deflated. With the PBDS vented, the additional shp over standard blades increases to 340 shp at 90 KCAS.

The increase in power required for level flight over the PBDS installed is a problem area. The increase in power required for level flight with PBDS installed should be reduced in future pneumatic deicer designs. During the PBDS activation cycle at 81 KCAS, engine power increased within two seconds to approximately 180 shp above the steady state value before PBDS activation and resulted in a four to five rotor rpm transient drop. The power increase equates to approximately 360 shp more than the standard UH-1H under similar gross weight and density conditions. The excessive power increase during the PBDS activation cycle in forward flight is considered a problem area which should be reduced with future pneumatic deicer designs. During level flight performance testing in the vented condition (failure mode of the PBDS), severe vertical vibrations were encountered at calibrated airspeeds above 92 knots. Testing at higher airspeeds in the vented condition was not attempted due to these vibrations. In the event of PBDS failure resulting in a vented condition, airspeed should be reduced below 80 KCAS and a landing made as soon as practicable.

(4). Autorotational descents were qualitatively evaluated in the vented configuration. The vented boot configuration would occur with an engine failure and subsequent loss of the bleed air pressure needed to provide the vacuum which keeps the boots deflated. After establishing a stable autorotational descent, the PBDS air supply was shut off at the regular-reliever/shut-off valve to establish the vented configuration which allowed the deicer boot to auto-inflate. Auto-inflation in this configuration results from differential air pressures and centrifugal forces acting on the boot. During the five to ten second period of auto-inflating, the autorotative rotor speed decreased by four to six rpm, but remained above the lower limit of 294 rpm (collective held full down). Steady state descent rates were approximately 800 to 900 feet per minute greater than those for standard blades. Prevention of deicer boot auto-inflation (vented condition) in case of engine failure would prevent rpm loss and lower descent rates during auto-rotation. A means of preventing auto-inflation should be developed prior to operational testing of the PBDS.

l. <u>Handling Qualities</u> -

(1) Handling qualities testing was conducted in conjunction with Phase I (structural) testing and Phase II (handling qualities and performance) testing. The handling qualities of the UH-1H helicopter with the PBDS installed were also qualitatively evaluated throughout the dry air testing.

(2) Control positions in trimmed ball-centered forward flight were evaluated from 36 to 98 KCAS with the PBDS in the deflated and vented conditions. The control position characteristics in trimmed forward flight are satisfactory and similar to standard UH-1H helicopters.

(3) The low-speed flight characteristics of the UH-1H helicopter with the PBDS installed were evaluated. Tests were performed at a constant skid height of ten feet in winds of five knots or less. Variations in the control positions during low-speed flight as a result of venting the boot are essentially the same as the PBDS deflated data and will not be addressed separately. Results are consistent with previously reported data on a standard and are satisfactory.

(4) The autorotational handling qualities were qualitatively evaluated during entry, steady state descent and during simulated autorotational landings which were terminated with a power recovery. These tests were accomplished with the PBDS in the vented condition simulating an engine failure at entry airspeeds of 70, 80, and 90 knots calibrated airspeed (KCAS). The autorotational handling qualities of the UH-1H with the PBDS installed are similar to standard UH-1H helicopter during steady state descent and simulated autorotational landings to a power recovery; however, increased descent rates will result in modification of the height velocity and glide distance charts for safe engine out operation of the test UH-1H.

(5) The response of the UH-1H during activation of the PBDS cycle was qualitatively evaluated during hover, low-speed flight and forward flight at airspeeds throughout the established flight envelope. Control fixed aircraft response was evaluated to determine the change in aircraft rates and attitudes under various flight conditions and pilot in the control loop controlling aircraft rate and attitude response was evaluated under similar conditions to determine the level of pilot effort required to control the aircraft during PBDS activation cycle. During a hover the controls fixed aircraft response to PBDS activation generally resulted in a moderate right yaw with rates up to 30 degrees per second. Very little roll or pitch attitude change was observed. This yaw rate was controlled three times by the pilot with the application of approximately 1/2 inch left pedal resulting in an initial heading excursion of ±10 degrees. With increasing airspeed, the yaw rate became less. Inputs required during activation of the PBDS in forward flight required moderate pilot compensation. The aircraft response to PBDS activation during hover and forward flight is a problem area. Vibration assessments using the VRS were qualitatively obtained at ten knot increments from 30 to 100 KCAS in level flight. Flight at airspeeds greater than 90 KCAS for extended time should not be conducted with the deicers in the deflated configuration due to moderate vertical vibrations encountered above 90 KCAS (VRS 6). With the deicers in the vented configuration airspeed should be kept below 80 knots and landing made as soon as possible. Activation of the PBDS at 90 KCAS and above resulted in severe vertical vibrations (VRS 7 and 8) for approximately eight seconds during inflation and the start of boot deflation. The PBDS should not be activated at airspeeds of 90 KCAS and greater due to severe vertical vibrations encountered at these airspeeds with the PBDS activated.

m. In-flight artificial icing tests were conducted during January and February 1983 at the NRC icing spray rig in Ottawa, Ontario, Canada, to evaluate the ice removal capabilities of the PBDS. The spray rig provided a cloud 75 feet wide by 15 feet high from a nozzle spray generated by 156 steam atomizing water nozzles. As shown in photo 2, the spray rig installation allowed hovering the test aircraft 20 to 30 feet above the ground while exposing the rotor system to the spray cloud when winds were greater than six knots. The cloud median volumetric diameter was reported to be 30 microns, and flow rate was adjustable to allow a maximum liquid water content (LWC) of 0.8 $gm/m^3$. Wind speed and gustiness impact uniformity of the cloud, affect estimation of LWC and changes in wind direction and gustiness move the cloud relative to the hovering aircraft, affecting consistency of rotor immersion. The temperature range of interest for these tests was -5 to -20°C, with LWC values as high as 0.75 $gm/m^3$. In determining a suitable test procedure, an ice thickness of 0.25 inch at the rotor blade mid-span (blade station 144, 12 feet from the hub) was selected as a baseline condition. Previous UH-1H test data of immersion times in the Ottawa

spray rig for this ice thickness were already available. To document ice accretions and deicing action of the PBDS in-flight, high-speed video and motion picture photography from the ground was used. After shutdown, visual inspection of ice coverage and shapes at mid-span and at the inboard end of the deicer boots (blade station 54) were made. Observations were recorded on data sheets and pertinent photographs were taken.

n. The artificial icing tests were performed at the temperature and LWC conditions shown in Appendix B-23. A total of 39 individual icing cloud immersions and 43 PBDS activation cycles were completed. Overall, the deicing capability of the deicer boots was satisfactory at all conditions tested in the spray rig. Two problem areas were identified during Phase III: (1) breakdown of internal pneumatic deicer ventilation material during blade rotation and (2) loss of regulated PBDS pressure during flight. Loss of regulated PBDS pressure was corrected at the test site during Phase III; however, internal breakdown of the pneumatic deicer will require further investigation by BFG. At accretion levels greater than 0.25 inches at mid-span, activation of the PBDS resulted in complete removal of the ice cap from the leading edge of the main rotor. All PBDS activations resulted in symmetrical ice sheds without increases in lateral vibrations. Activation of the pneumatic deicer boots after natural asymmetrical ice sheds reduced the associated vibration within two seconds and is an enhancing characteristic. Aircraft power required increases experienced during deice cycles were the same as seen during hover performance. Limited flight testing was conducted at -5C; however, natural ice shedding occurred frequently enough that PBDS activation was not necessary. All single deice cycles resulted in clean blades without residual ice remaining on the deicer boot. The outboard section (past blade station 192) may be self-shedding prior to accreting 0.25 inches at the midspan during icing tests.

28. USAAEFA Project No. 82-12, Evaluation of UH-1H Hover Degradation Performance Caused by Rotor Icing (Reference A-34, Appendix A).

a. AVSCOM and the NASA/ Lewis Research Center (LeRC) jointly started a program to predict the hover performance penalties associated with helicopter operations in icing conditions. The phases of the program include flight test, wind tunnel tests, and computer modeling. The Aeronautical and Astronautical Research Laboratory of Ohio State University (OSU) was contracted to document the ice shapes obtained during flight tests, and conduct subsequent wind tunnel experiments on the shapes. Bell Helicopter Textron (BHT), Texas Agricultural and Mechanical University (Texas A&M), and NASA/Ames Research Center (ARC) were contracted to analyze the combined flight and wind tunnel data and develop the mathematical algorithms required to predict hover performance degradation caused by rotor icing.

b. The flight test portion of the program consisted of gathering hover performance data with both clean and iced rotor blades, and documenting the topography of the ice accretion. The icing tests were conducted using a UH-1H helicopter at the Canadian National Research Council (NRC) Icing Spray Rig in Ottawa, Canada.

c. The objective of the flight tests were to gather comparative hover performance and blade surface topography data for the UH-1H helicopter with both clean and iced rotor blades. Because the NRC Icing Spray Rig requires a minimum wind velocity of six knots, true hover data in still air would not be possible;

therefore, a secondary objective was to evaluate the low-speed performance characteristics of the aircraft.

d. The UH-1H is a thirteen-place single engine helicopter using a single two-bladed teetering main rotor and a two-bladed tail rotor. The maximum gross weight is 9500 pounds. Power is provided by a Lycoming T53-L13B free turbine engine rated at 1400 shaft horsepower (shp) at sea level standard day conditions. The main rotor transmission is limited to 1100 shp for continuous operation. The test aircraft, U.S. Army S/N 69-15532, is a standard production UH-1H equipped with test instrumentation, a rotor brake, and a heated windshield. Instrumentation and special equipment is shown on Appendix C-22.

e. Icing flights were conducted at the NRC Icing Spray Rig at Ottawa (elevation 374 feet) between 28 January and 4 March, 1983. Eleven flights were made totalling 8.1 hours. Eight low-speed and hover flights, totalling 8.4 hours were made at Edwards Air Force Base, California, (elevation 2303 feet), between 22 April and 6 June, 1983. A summary of the icing test rig conditions is presented in Appendix B-24.

f. The intent of this program was to provide data for correlation of hover performance degradation with specific ice contours. The first technique attempted was to fly several tethered hover points, release the tether, enter the ice cloud and gather ice, exit the cloud, attach the tether, and repeat the tethered hover points. However, the flexing of the rotor blades during the second series of hover points shed most of the ice accreted in the cloud.

g. The techniques finally established was to:

(1) Determine baseline profile power required by doing a flat-pitch ground run at several rotor speeds.

(2) Fly a baseline out-of-ground effect (OGE) free hover point.

(3) Enter the cloud, accrete ice, and exit the cloud.

(4) Fly another free hover point to determine hover performance degradation.

(5) Repeat the flat-pitch ground run to determine the increase in profile power caused by icing.

(6) Document the ice shapes.

This technique allowed the ice to remain on the blades without shedding.

h. Ten flights behind the rig were made, with ice being retained on five. Each successful icing flight was assigned a letter by NASA/Lewis. Flight conditions are shown in Appendix B-24. Above a temperature of -9.5°C, adequate ice could not be retained.

i. The icing spray rig requires a minimum of six knots wind to form a cloud a safe distance from the rig itself; therefore, it is impossible to obtain true hover data while the rig is in operation. Additional low-speed flights were flown at Edwards Air Force Base to provide data relating hover and low wind speed performance.

j. Ice Documentation -

(1) OSU had general management responsibility for the documentation of ice shapes. Arvin/Calspan Field Services, Inc., at Arnold AFS, Tennessee, had the responsibility for the research and development of stereoscopic photography techniques and complete interpretation. A local Ottawa firm, Hovey and Associated (1979) Ltd., actually performed all the documentation activities at the ice rig. The three documentation methods used were molding, tracings, and stereoscopic photography.

(2) All the documentation efforts took place in a special work platform; a modified airline galley truck borrowed from Air Canada. The truck had inside dimensions of 20 feet long by 7-1/2 feet wide by seven feet high with a four foot wide door. Modifications to the truck included installing three 100 vac duplex outlets, four 750 watt, 220 vac space heaters, and a 1500 watt, 110 vac heater. The rotor blade being documented was positioned perpendicular to the aircraft centerline, and the work platform was backed up so the blade was within the truck. The blade tip was then secured to the platform with a fixture. The door was partially closed vertically from the top and a tarp was attached below the door to seal the truck from the outside conditions. The heaters were used to slowly increase the temperature to a maximum of -5°C.

(3) A stereo-photogrammetic technique developed by Arvin/Calspan Field Services, Inc., for the Arnold Engineering Development Center (AEDC) of the Air Force Systems Command was one of the methods used to document the ice formations on the rotor blade. In this technique, wide-angle stereo photographs of the test contour were taken by two cameras oriented on converging axes while the target was illuminated by a projected grid pattern. An additional target screen fixture with marked control points at known coordinates was placed within the field-of-view over the blade. By referring to the projected grid, the control point rig, and markings on the blade itself, a computer assisted analysis of the ice shape photographs could be performed to numerically define the contour both in general shape (profile) and fine scale (roughness).

(4) Each photographic pair was obtained with two 70mm Hasselblad cameras equipped with 50mm lenses attached to a mounting fixture. Black and white Kodak Plus-X Pan (2147) film was used, and the film magazines were modified to ensure that the film was held flat by a vacuum pump during the simultaneous exposures. The mounting fixture separates the camera lenses by 24 inches horizontally. Once the iced rotor blade was positioned inside the work platform and secured at the tip, the camera rig was situated facing the leading edge of the airfoil at a distance from 18 to 21 inches. The control point rig, consisting of two flat surfaces perpendicular to each other and marked with a pattern of dots, was positioned over the rear of the rotor blade to form the fixed target with known coordinates.

(5) A central flash unit located between the cameras projected a grid pattern onto the blade and target, and two synchronized strobe units adjacent to the cameras provided additional illumination to the sides. To provide a better image of the projected grid, the surface of the ice was lightly dusted with a white talc-like powder prior to photography. The rotor blades had one inch wide white stripes painted at one ft intervals along the span, and a pattern of four black dots were spaced 1 1/2 inches apart on the stripes, starting 3 1/2 inches aft of the leading edge on both upper and lower blade surfaces.

(6) These stereo pairs were taken along the iced span of the blade centered on every second foot-wide segment between the stripe markings. The most inboard segment accessible within the work platform was five feet from the hub. A series of three photographs were made at each location as the cameras were adjusted vertically: in the chord plane, and approximately one foot above and below the chord plane.

(7) A representative series of photographs from the stereo cameras is shown in photos 8 through 11 of reference 27, Appendix A. These show the ice formations resulting from test flight "E" at blade stations 102 and 222 (8.5 and 18.5 ft from the hub, respectively). Left and right stereo pairs taken from above and beneath the rotor plane are presented. These photographs show the ice accretion, the rotor blade marked with stripes and reference dots, the control point rig with its pattern of target dots, and the projected grid.

(8) Analysis by AEDC of the stereo pair photographs was done by reading coordinates with the analytical stereo-compiler directly from the original negatives. The numerical data transmitted to the AEDC computer could then be transformed or rotated within selected coordinate axes as desired for further manipulation.

(9) After the stereo photos were taken, a hot wire electric "knife" was used to cut a cross section of the ice shape at two foot intervals along the span of the accreted ice. A template was then inserted against the blade, and a pencil tracing was made of the ice shape. The tracings are accurate, and since they can be made quickly and easily, the tracing technique is a valuable documentation method.

(10) One foot wide plywood mold frames were placed around the blade at two foot intervals along the span of accreted ice. Approximately 1.7 kg of room temperature vulcanizing (RTV) silicone molding compound was poured into each frame, and allowed to cure for three hours. Heating pads were placed around the molds after the first hour. The compound was made of one part Dow Corning RTV 3110 base, 1/9 part No. 200 thinner, and 1/150 part No. 4 catalyst. Slightly more catalyst was used when temperatures were below 10°C.

(11) The base and thinner were pre-measured in five kg batches, put into buckets, and stored in an unheated building. Approximately 30 minutes before use, the catalyst was added, and the compound was mixed with an electric drill and paint mixer attachment or paddle. The buckets were then placed in a vacuum chamber for 15 minutes to remove excess air.

(12) The compound was made relatively thin to fully contour the ice shapes during molding. The molds set to the point they could be removed from the rotor blade in about three hours. They were normally removed from the mold frames the following day. The ends of each mold were cut off to assure a clean cross-section. The resulting molds covered approximately four inches on the top of the blade, five inches on the bottom, and ten inches in span. The molds produced very accurate ice shape contours and the molding operation was fully successful.

k. Profile Drag -

(1) Ice formation on the rotor blades will increase the profile drag. Before and after accreting ice on every flight, the aircraft was run on the ground at several rotor speeds and zero collective. Main rotor torque was measured, and main rotor power was calculated. Profile power (the power required to pull the blade through the air) varies linearly with the cube of angular velocity. Flights C and D are not shown because the main rotor torque instrumentation was inoperative. The data show an increase in profile power at normal speed and sea level standard density of approximately 25 horsepower for the ice accreted in Flight A (0.2 inches at midspan), 45 horsepower in Flight B (0.3 inches), and 60 horsepower in Flight E (0.4 inches).

(2) Temperatures for these datum points ranged from -9.5°C to -19°C. Blade tip Mach Numbers ranged from 0.70 (290 rpm at -9.5°C) to 0.79 (324 rpm at -19C). Part of the profile power can be attributed to compressibility at these relatively high Mach numbers. A significant advantage of presenting incompressible power data is that the linear fairing through all data passes through the zero rpm, zero power point. This, in turn, allows $Cp_o$ (profile power coefficient) to be represented by a constant throughout the rpm range. $Cp_o$ is the non-dimensionalized slope of the linear fairings on Table 1. The average profile drag coefficient ($Cd_o$) is a linear function of $Cp_o$.

(3) The measure of profile power and its non-dimensional counterparts showed increasing profile drag with greater ice accretion. The data consistency gives reason for a relatively high confidence level in the data presented.

Table 1. Incompressible $Cd_e$ with Accreted Ice

| Flight | Ice Thickness at Mid-Span (inches) | $Cp_o$ x $10^5$ | $Cd_o$ |
|---|---|---|---|
| Baseline | 0.0 | 5.28 | .0091 |
| A | 0.2 | 5.75 | .0099 |
| B | 0.3 | 6.04 | .0104 |
| E | 0.4 | 6.40 | .0110 |

l. Hover Performance Degradation -

(1) Tethered hover performance flights were performed at Ottawa and Edwards AFB in winds of less than two knots. The data were compared to previous UH-1H data and matched very closely.

(2) Hover performance data for the UH-1H characteristically show scatter. Large quantities of data are gathered to attain a statistically significant curve, which can then be presented with confidence. During these icing tests a single free hover point was flown before and after each ice accretion. The data consistently show greater power required with ice than with-out ice, but the magnitude of the increase does not correlate with the

quantity of ice accreted. The lack of correlation may be caused by normal hover performance data scatter. The best way to obtain hover performance test data with accreted ice is to take a statistically significant number of datum points; however, this cannot be done without shedding the ice during the test. A possible alternative would be to attach imitation ice forms to the blades and then conduct a performance test.

m. Conculsions -

(1) Tethered hover testing causes shedding of accreted ice.

(2) Adequate ice formation could not be retained at ambient temperatures above -9.5°C.

(3) All ice documentation methods: stereoscopic photography, tracings, and molds, worked well and provided accurate ice contours.

(4) Changes in profile power caused by rotor icing could be measured consistently during ground runs, and was the most valuable indicator of performance loss.

(5) Performance degradation caused by rotor icing in a hover could not be correlated with quantity and accreted ice using a single free hover point.

(6) Hover performance degradation data must be gathered in sufficient quantities to be statistically significant.

(7) Low speed performance data were obtained.

29. USAAEFA Project No. 83-23, Evaluation of UH-1H Level Flight Performance Degradation Caused by Rotor Icing (Reference A-35, Appendix A).

a. AVSCOM and NASA/Lewis Research Center (LeRC) are jointly started a program to predict the performance penalties associated with helicopter operations in icing conditions. Included in the program are flight tests, wind tunnel tests, and computer modeling to evaluate the relationship between the rotor ice shapes and performance degradation. The Aeronautical and Astronautical Laboratory of Ohio State University (OSU) was contracted to document the ice shapes obtained during the flight tests, and conduct subsequent wind tunnel experiments on the shapes. Bell Helicopter Textron (BHT), Texas Agricultural and Mechanical University (Texas A&M), and the NASA/Ames Research Center (ARC) were contracted to analyze the combined flight and wind tunnel data and develop the mathematical algorithms required to predict performance degradation caused by rotor icing. The initial phase of the ATL/LeRC effort required USAAEFA to gather hover performance data with both clean and iced main rotor blades. Hover tests were conducted at the Canadian National Research Council Icing Spray Rig at Ottawa, Ontario, Canada, in 1983.

b. The objective of this test was to gather comparative level flight performance and blade surface topography data for the UH-1H helicopter with both clean and artificially iced main rotor blades.

c. UH-1H is a thirteen place, single engine helicopter using a single two-bladed teetering main rotor and a two-bladed tail rotor. The maximum gross weight is 9,500 pounds. Power is provided by a Lycoming T53-L-L3B free turbine

engine rated at 1,400 shaft horsepower (shp) at sea level standard day conditions. The main rotor transmission is limited to 1100 shp for continuous operation. The test aircraft, U.S. Army S/N 69-15532, is a standard production UH-1H equipped with test instrumentation. The HISS was flown in the 1984 configuration. Instrumentation and special equipment is shown in Appendix C-23.

d. Artificial icing tests were conducted at Duluth International Airport, Minnesota, between 25 February and 9 March, 1984. Nine flights were made totalling 10.1 hours. On eight flights, the ice shapes were documented, and NASA flight letters A through H were assigned. The test aircraft was also used by USAAEFA Project No. 81-01 during this time period. The portion of the shared flight time charged to this project totalled an additional 18.4 hours. Test conditions are shown in Appendix B-25.

e. The intent of this program was to provide data for correlation of level flight performance degradation with specific ice contours. The test sequence is described below.

(1) A zero side-slip level flight performance polar was flown at a specified thrust coefficient ($C_T$) before the test aircraft entered the HISS cloud. $C_T$ was maintained by using the constant referred gross weight, constant referred rotor speed method.

(2) After the level flight polar, the aircraft would climb approximately 800 feet to compensate for fuel burnoff expected during icing. The HISS and the U-21 then established the proper cloud conditions.

(3) The main rotor of the test aircraft was then iced at 90 knots true airspeed (KTAS) for a specified period of time. The spanwise accretion was observed from the U-21.

(4) After the rotor was iced, the aircraft exited the cloud and several different speeds on the level flight polar were repeated. The repeat test conditions took approximately nine minutes to complete. The flying of the repeat test was planned so that the aircraft was close to the airport upon completion.

(5) The aircraft was landed directly on the ramp where the ice documentation was to take place. Time from completion of the data to touchdown was between two and three minutes. The engine was shut down without the normal two minute cool-down period, and the rotor was stopped using the rotor brake. The time from touchdown to rotor stoppage was less than one minute.

(6) The ice shape on the rotor blade was documented.

f. Ice Shape Documentation - The ice shape documentation efforts were performed by FluiDyne Engineering Corporation of Minneapolis, Minnesota, under contract to OSU. A self-propelled, 7 x 20 feet scissor-lift platform was used as a work station by the FluiDyne personnel. One foot-wide silicone rubber molds were made of the ice shapes at two foot intervals along the span of the blade. Because of the 12 to 13 minute interval between exiting the ice cloud and rotor stoppage, there was concern that some of the ice had eroded or sublimated before the shape could be documented. Flight H was flown without gathering any performance data, and was planned to reduce the time interval between

cloud exit and rotor stoppage to two minutes. There was no apparent improvement in the level of fine detail on the accreted ice from Flight H compared to the other flights at similar ambient temperatures. The RTV molds produced by FluiDyne showed excellent detail of the ice shapes. All the molds were shipped by FluiDyne to OSU at the completion of the test. OSU will produce male castings from the molds and perform wind tunnel analysis. The molding material is very heavy and flexible, and does not hold its shape.

g. <u>Performance</u> - Performance data comparing clean and iced rotor blades were taken on flights A through G. The customary way to present quantity of ice accreted on a rotor blade is to measure the mid-span ice thickness. Ice thicknesses were measured at mid-span (12 feet) by FluiDyne. Flights A through C exposed the blades to the ice cloud for approximately five minutes and accreted mid-span ice of approximately 1/4 inch. Performance was degraded slightly. At 100 KTAS, main rotor power increased by 25 horsepower (hp) in flight A. The increases in power for flights B and C were negligible. Flights D and E demonstrated the inadequacy of one-dimensional descriptions of ice shape to predict degradation. Even though the blades in flight D had accreted less mid-span ice than in flight E, the performance degradation was considerably greater (98 hp main rotor power at 100 KTAS compared to less than 5 hp). The HISS cloud during flights E and G contained unusually large water droplets which is not representative of clouds found in nature; therefore, the ice shapes created by the cloud may not be representative of shapes found while flying in natural icing conditions. However, the data presented are valid for the ice shapes obtained. As with flights D and E, there is no correlation between one-dimensional ice thickness and performance degradation. The ice shapes obtained during flights D and F, unlike those obtained in flights E and G, are characterized by significant protuberances ("rams and horns"), which greatly alter section aerodynamic characteristics. The ice shapes from flights E and G are considerably more conformal, and therefore, do not degrade aircraft performance to nearly the same extent. The data obtained during these flight tests were obtained more quickly than would normally be done during a level flight performance test. This was necessary because of the requirement to land as soon as possible after leaving the icing environment. Baseline data were obtained for every flight to assure that direct comparisons could be made between iced and clean rotor blades. The data are consistent within data sets. The lack of correlation between simplistic one-dimensional ice shape description and performance degradation is valid; and the results confirm the requirement for full scale three-dimensional ice shape documentation and analysis.

30. USAAEFA Project No. 81-18, UH-60A Light Icing Envelope Evaluation with the Blade Deicing Kit Installed but Inoperative <u>(Reference A-36, Appendix A)</u>.

a. The U.S. Army requires the UH-60A helicopter to operate safely in a moderate icing environment with a deicing system installed. Arti-ficial icing tests were previously conducted in Alaska in 1976 by the USAAEFA using a prototype YUH-60A with main and tail rotor deice system and anti-ice provisions for the pilot and copilot windshields, pitot-static tubes and their support struts, engines and engine inlets. Tests of a production UH-60A with similar deice and anti-ice systems, were conducted in Minnesota in 1979, 1980, and 1981. The current UH-60A helicopter fleet of approximately 200 aircraft does not have the production deicing kit which includes an ice detector and rate meter as a part of the configuration. A requirement exists for UH-60A helicopters that are not equipped with the deicing kit to fly under light icing conditions; however, it

was essential to first verify a light icing envelope (up to 0.5 grams per cubic meter ($gm/m^3$) liquid water content (LWC) for this configuration. The objective of this test was to conduct artificial and natural icing flight tests to establish the maximum icing envelope for the UH-60A with an inoperative blade deicing kit.

b. The UH-60A is a twin-turbine, single-main-rotor configured helicopter capable of transporting cargo, 11 combat troops, or weapons during day and night, visual, and instrument meteorological conditions (IMC). Nonretractable wheel-type landing gear are provided. The main and tail rotors are both four-bladed, with a capability of manual main rotor blade and tail pylon folding. The test aircraft S/N 78-22976 was a production UH-60A, second year buy, with a production deicing kit (P/N 70070-30003-013) modified for this test. The main and tail rotor deice systems were the same as the production deice systems, except the deice controller was modified for flight safety reasons to allow the blades to begin their deice cycle with the heating element ON immediately upon turning the system on rather than starting the deice cycle with the element OFF. The ship's Rosemount ice detector and rate meter were modified to permit their operation with the deice system power switch OFF.

c. In-flight artificial and natural icing tests were conducted in the vicinity of St. Paul, Minnesota, from 29 January to 1 April, 1982. A total of eight icing flights were conducted totaling 16.3 hours. Four artificial icing flights totaling 4.2 productive hours, and four natural icing flights totaling 4.8 productive hours were conducted. The aircraft was flown in the normal utility configuration. Average density altitude varied from 2,600 to 7,000 feet. Icing was accomplished at ambient temperatures from -4.0 to -15.0°C at average liquid water contents (LWC) of 0.15 to 0.5 $gm/^3$. Test airspeeds ranged from 97 to 125 knots true airspeed (KTAS) and the main rotor speed was 258 rpm. Test conditions are shown in Appendix B-26. Instrumentation and special equipment are shown in Appendix C-24.

d. <u>Flignt Control Surface Ice Acretion and Shedding Characteristics</u> -

(1) Main rotor ice sheds occurred in both the artificial and natural icing environments. The ice accretion and shedding characteristics of the main rotor blades was independent of leading edge surface condition. The first ice shed during a flight typical occurred from 17 to 52 minutes after entering the icing environment with random and more frequent sheds occurring thereafter. The time required for the first shed to occur and the frequency of subsequent sheds appeared to be a function of the LWC and ambient outside air temperature.

(2) The main rotor ice sheds resulted in light to moderate increases in airframe vibration which normally lasted less than a minute. This increased vibration level was barely apparent to an experienced aircrew fully occupied by their tasks and, on occasion, noticeable only if their attention was directed to it or when not otherwise occupied (Vibration Rating Scale (VRS) 3 to 4). One main rotor ice shed occurred during artificial icing at 0.5 $gm/m^3$ LWC and -12.5°C which resulted in an airframe vibration immediately apparent to the aircrew, but did not significantly affect their workload over the length of time the vibration lasted (approximately ten minutes) (VRS 6). Significant airframe damage also occurred from main rotor ice hitting the fuselage during this icing encounter. The increase in airframe vibration due to main rotor ice shedding was satisfactory.

(3) Engine torque increased with ice accretion and decreased when ice was shed from the rotor system. Accurate measurement of torque increase/decrease was not possible while flying in the artificial icing environment due to constant collective control changes required to fly formation and keep the main rotor positioned in the HISS cloud; therefore, an estimate of the percentage of torque rise in the artificial icing environment could not be made. A fixed collective setting was used while in the natural icing environment permitting a more accurate correlation between torque increases/decreases and rotor blades surface ice accretion/shedding. The largest torque rise was observed in natural icing conditions at 0.5 gm/m$^3$ LWC -4.0°C; however, major engine damage occurred during this flight due to ice ingestion from a rotor ice shed. The largest torque rise without airframe damage or droop stops failing failing to seat properly occurred at conditions of 0.1 and 0.2 gm/m$^3$ LWC and -15.0°C. The first main rotor shed began at 43 minutes after entering the icing condition and was completed at 49 minutes, resulting in a three percent torque decrease per engine, leaving a residual five percent torque per engine increase above the pre-immersion cruise torque. A second torque rise of four percent occurred during the 30 minutes after the first shed resulting in a nine percent torque increase above the pre-immersion cruise torque. A subsequent shed caused a five percent torque reduction. The maximum torque rise was nine percent per engine and occurred at 63 minutes after entering the icing environment. Of this 63 minutes, 38 minutes were at 0.1 gm/m$^3$ and 25 minutes at 0.2 gm/m$^3$ LWC. The nine percent torque increase above the trim cruise power will mean reduced range and endurance compared to the aircraft being flown in a non-icing environment and will impact IMC mission planning. The turbine gas temperature (TGT) remained within the normal continuous limits during these power increases at 15,940 pounds gross weight, and 5760 feet pressure altitude; however, at heavier weights in similar icing conditions, the TGT may be within the 30 minute limit range and could reach the maximum TGT limit.

(4) Autorotation rotor speed was evaluated after exiting the icing condition with the residual five percent torque increase noted in the above paragraph. The autorotation rpm was within the tolerances specified in the UH-60A Maintenance Test Flight Manual for the ambient conditions. The autorotation rpm was within the proper range when checked after other icing encounters; however, conditions did not permit an autorotation rpm check at the maximum nine percent or the 18 percent torque increase.

(5) Visual observation of the tail rotor blades after icing encounters revealed no significant ice accretions. A hi h frequency vibration was felt in the cockpit after exiting the natural icing nditions of 0.1 to 0.2 gm/m$^3$ LWC and -15.0°C. This vibration was apparent to the crew but did not increase their workload over the short period of time the vibration occurred (VRS 4).

(6) Unheated droop stops and flap restrainers were evaluated throughout the icing tests for proper positioning during main rotor shutdown. Government competitive tests (GCT) droop stops (P/N 70105-08051-101) were used during this test because they demonstrated the best ice accretion characteristics of the droop stops tested during previous evaluations. After landing from this natural icing flight, only 0.5 inches remained of the 3.25 inches in-flight ice accumulation on the main rotor head due to encountering temperatures above freezing after exiting the icing environment. These droop stops probably would have remained in the "flight" position during shutdown if the outside air temperature had been below freezing. This does not present a significant problem to the

ground crew if properly briefed prior to engine shutdown; however, if a shutdown is necessary in high or gusty wind conditions, the main rotor blades may strike the tail rotor drive shaft in the vicinity of the tail rotor intermediate gear box.

(7) The aircraft sustained damage during flights under both artificial and natural icing conditions. During an artificial icing flight at 0.49 $gm/m^3$ LWC and -6.0°C, a tail rotor blade tip cap was damaged, requiring replacement. During another artificial icing flight at 0.5 $gm/m^3$ LWC and -12.5°C, several components were damaged. The white strobe portion of the upper anti-collision light was broken by ice shed from the main rotor. The shattering glass from the anti-collision light was thrown into the tail rotor blades causing damage to the leading edge of all four blades. Additionally, the tail rotor gear box fiberglass cowling was hit by ice shed from the main rotor causing a dent approximately nine inches in diameter and four inches deep. The cowling was split approximately six inches.

(8) The final test flight was in natural icing conditions of 0.5 $gm/m^3$ LWC and -4.0°C. Vibration data from this flight, which is typical of other flights, indicate larger increases in longitudinal vibrations than in the other axes. A 17 percent torque rise per engine occurred after the aircraft had been in the icing environment 13 minutes. At 29 minutes, a main rotor ice shed occurred and torque decreased to the pre-immersion trim power required for cruise (collective fixed). Within five minutes after this shed, the torque had increased 14 percent per engine with random main rotor ice sheds occurring every three to five minutes, resulting in torque decreases of three to four percent. significant increase in vibration level was noted during the ice sheds. After 43 minutes in the icing condition, torque was 18 percent above trim pre-immersion cruise power. At this time, ice was shed from the main rotor and ingested into the No. 2 engine, causing a rumble, similar to that of a compressor stall, accompanied by a high pitched squeal and TGT increase of approximately 40°C. The icing condition was exited immediately and the aircraft was landed at an outlying airport. This flight produced the highest torque rise and most costly aircraft damage of any icing condition tested. A borescope inspection revealed major damage to the compressor section of the No. 2 engine requiring engine replacement.

(9) The main rotor ice shedding characteristics discussed in the two preceeding paragraphs resulted in aircraft damage. No aircraft damage occurred at any conditions tested with 0.3 $gm/m^3$ LWC or less; however, the potential exists for aircraft damage due to ice sheds at LWC's above 0.3 $gm/m^3$. Aircraft damage occurring from rotor system ice sheds at LWC's of approximately 0.5 $gm/m^3$ constitutes a deficiency. The UH-60A should not be cleared for operation in icing conditions more severe than 0.3 $gm/m^3$ LWC without a qualified deice kit installed and operational.

e. Performance Vibration and Handling Qualities - There are no handling qualities, visual, or performance pilot cues which would indicate the severity of the in-flight icing conditions on the UH-60A with the blade deicing kit removed. The only way the crew can be made aware of the severity of the icing conditions in which they are flying, before aircraft damage occurs is to have an

operable ice detector and ice rate meter installed on the aircraft. The UH-60A helicopters, without a blade deice kit, should have an ice detector and ice rate meter installed before they are cleared to fly into forecast icing conditions.

31. USAAEFA Project No 83-21, Artificial and Natural Icing Tests YEH-60A Quick Fix Helicopter (Reference A-37, Appendix A).

a. The UH-60A, with production deicing kit installed, has undergone natural and artificial icing airworthiness flight tests and has been cleared for flight into moderate icing conditions. The YEH-60A helicopter Quick Fix System consists of UH-60A helicopter modified to accept an AN/ALQ-151(V)2 countermeasures system. Artificial and natural icing tests were required to quality the helicopter, in this configuration, for flight in moderate icing conditions.

b. The primary objective of this test was to conduct limited artificial and natural icing flight tests to provide AVSCOM the basis for establishing a moderate icing envelope for the YEH-60A helicopter Quick Fix System. An additional objective of this test was to determine the effectiveness of electrically anti-icing the direction finding (DF) antennas.

c. The UH-60A is a twin-turbine, single main-rotor helicopter capable of day and night operations under visual and instrument meteorological condition (IMC). Non-retractable wheel type landing gear are provided. The main and tail rotors are both four-bladed, with a capability of manual main rotor blades and tail pylon folding. A UH-60A with the deicing kit installed incorporates a main and tail rotor deicing system and an ice detection system as well as anti-icing for the pilot and copilot windshields, pitot static tubes and their support struts, engines and engine inlets. The test helicopter (S/N 79-23301) was equipped with improved main rotor droop stops (FSN 70105-08151-045). The YEH-60A Quick Fix System consisted of a UH-60A modified to accept an AN/ALQ-151(V)2 countermeasures system. The AN/ALQ-151(V)2 system electronics are contained in two rack assemblies and two operator console assemblies located in the helicopter cabin. The Quick Fix System antennae included two UHF antennas mounted on the underside of the fuselage; one retractable electronics countermeasures (ECM) antenna installed on the underside of the fuselage just forward of the transition section; a DF dipole antenna set mounted on the exterior of the tail cone; and a built-in test equipment antenna located on the rear vertical section of the tail. For a portion of the evaluation, an electronically anti-iced DF antenna replaced one of the standard DF antennae on the right side of the aircraft. The test YEH-60A was also equipped with the cruise infrared (IR) suppressor kit; the AN/ALQ-144 Infrared Countermeasures Set; the AN/APR-39 Radar Signal Detecting Set; and two M-130 Chaff/Flare Dispensers. The HISS was flown in the 1983 configuration.

d. In-flight artificial and natural icing tests were conducted in the vicinity of Duluth, Minnesota, from 6 January to 21 March, 1984. A total of 11 icing flights were conducted totaling 12.3 hours. Of these flights, six were in the artificial icing environment, totaling 4.5 hours, and five were in the natural icing environment totalling 7.8 hours. A 0.9 hour flight was also flown to investigate possible Electromatnetic Interference (EMI) between the helicopter's blade deice system and Quick Fix mission electronics. Average density altitude varied from 830 to 7630 feet. Icing was accomplished at ambient temperatures from -22.5°C to -4°C at average liquid water content (LWC) of 0.15 to 1.16 grams per cubic meter (gm/m$^3$. Test airspeeds ranged from 93 to 131

knots true airspeed (KTAS) and the main rotor speed was 258 rpm Anti-ice and deice systems were operated continuously while in the icing environment. Flights were conducted with the AN/ALQ-144 Infrared Jammer and IR suppressor kit installed. A summary of icing test conditions is presented in Appendix B-27. Instrumentation and special equipment are shown in Appendix C-25.

e. Flight Control Surface Ice Accretion and Shedding Characteristics -

(1) Rotor system ice accretion and shedding characteristics were evaluated throughout these tests. No in-flight difficulties associated with control surface ice accretion or shedding were identified. Following flight in both natural and artificial conditions, the droop stops returned to the retracted (shutdown) position. Tail rotor tip caps were damaged during flights under both artificial and natural icing conditions.

(2) The ice accretion and operational characteristics of the droop stops were evaluated throughout these tests. The droop stops installed on the test aircraft were referred to by the improved droop stop configuration and this configuration differed from previously tested droop stops (reference 3, Appendix 4) in that the tungsten washers were removed, the arms thickened and shortened, and the rubber bumper removed.

(3) Tail rotor tip caps were damaged during flights in both artificial and natural conditions. During a natural icing flight at -5.5°C and LWC of 0.25 $gm/m^3$, two tail rotor tip caps were damaged and required repair. During an artificial icing flight at -6.5°C and LWC of 1.0 $gm/m^3$, another tip cap was damaged requiring repair. In neither case did the damage cause a noticeable increase in vibrations nor change in aircraft handling characteristics. Ice impact damage to the tail rotor tip caps is a shortcoming.

(4) The airframe ice accretion and shedding characteristics of the YEH-60A Quick Fix helicopter were evaluated in both the original configuration and with a prototype, thermo-electrically anti-iced DF dipole antenna installed. Ice formed on all stagnation areas and sharp protrusions from the airframe. Ice did not form on the anti-iced portions of the prototype heated DF dipole antenna.

(5) The ice accretion characteristics of the unheated DF dipole antennas were evaluated. Ice accumulation caused the unheated DF antennas to oscillate. Flight in artificial icing conditions (1.0 $gm/m^3$ LWC at -20.0°C) was terminated after 28 minutes behind the HISS when the chase aircraft observed ±4 inch tip oscillations of the DF antenna elements. Post flight measurement recorded 1.5 inches of ice on portions of the DF antenna elements. No damage to the DF antennas or their mounts was noted; however, post flight inspection of the DF antennas after 74.5 minutes in natural icing conditions (0.35 $gm/m^3$ LWC at -11.0°C) revealed that the phenolic support block of the front right DF antenna (#3) had cracked and the mounting screws for the antenna elements of the rear right antenna (#4) had loosened. Further testing of the unheated antenna configuration was suspended following this flight. The effect of ice accumulation on the DF capability of the system was not tested.

(6) The ice accretion characteristics of a thermo-electrically anti-iced DF dipole antenna were evaluated. Before starting icing tests, the anti-iced antenna was flown in clear air and antenna surface temperature

recorded as a function of airspeed and altitude. The anti-iced DF antenna was mounted in position #3, the aft antenna mount on the right side of the tail cone. All other DF antennas were removed for subsequent icing tests. The antenna's anti-ice protection was provided by 900 watt heater elements bonded inside each antenna element. Heated operation was manually controlled by cabin and cockpit mounted switches. No ice accumulation was noted on the heated portions of the DF antenna elements during flight in either natural or artificial conditions. No antenna oscillations were observed in artificial or natural icing conditions or in clear air tests. The anti-iced DF dipole antenna was designed only to test the feasibility of antenna anti-icing and was not configured to DF. No electromagnetic interference was noted between the heated DF dipole antenna elements and other aircraft systems. The thermo-electrically anti-iced DF dipole antenna demonstrated safe operation in icing intensities, though moderate.

(7) The ice accretion and shedding characteristics of the ECM antenna were evaluated. The ECM antenna was iced in the retracted and extended positions. Ice accumulation induced an oscillation on the ECM antenna causing tip deflections of up to ±1 foot, just prior to self shedding. The oscillation also caused noticeable movement of ECM antenna actuation mechanism and the adjoining mounting structures. The oscillations occurred approximately every 10 minutes in moderate icing conditions. They usually lasted between 10 and 30 seconds and ended when the accumulation ice was shed. Shedding could also be induced by retracting and extending the ECM antenna. In the retracted position, the ECM antenna and its actuation mechanism accumulated only small amounts of ice which did not prevent antenna extension or retraction. Post flight inspections revealed no damage to the antenna or the mount following icing encounters. The operational characteristics of the ECM antenna after ice accumulation or while oscillating were not evaluated.

(8) The YEH-60A Quick Fix helicopter has two M-130 chaff/flare dispensers mounted on the left side of the tail cone just aft of the transition section. The ice accretion and shedding characteristics of these dispensers were evaluated. The M-130 systems were not operated during this evaluation. No ice accretion or subsequent sheds were observed which would interfere with the operation of the system during or after an icing encounter.

(9) The ice accretion and shedding characteristics of the ALQ-144 IR Countermeasures device were evaluated. For most test flights, the ALQ-144 was activated before entry into the icing conditions. To test the capability of the device to shed accumulated ice, the ALQ-144 was also activated after an artificial icing encounter of 43 minutes at -6.5°C, and the average LWC of 1.0 $gm/m^3$. Activation of the ALQ-144 melted the ice touching the lens and the remaining ice shed naturally. Evaluating the effects of ice accumulation on the operating characteristics of the ALQ-144 was beyond the scope of these tests. The ice accumulations and subsequent sheds from the ALQ-144 after exposure to natural and artificial icing conditions did not adversely effect the operation of the aircraft.

32. USAAEFA Project No 83-22, Limited Artificial and Natural Icing Test of the External Stores Support System (ESSS) Installed on a UH-60A Helicopter (Reference A-38, Appendix A).

a. The UH-60A helicopter, with the production deicing kit installed, has undergone natural and artificial icing airworthiness qualification flight tests and has been cleared for flight into moderate icing conditions. The External Stores Support System (ESSS) is designed to meet a requirement for a self-deployment capability for the UH-60A. The ESSS allows the UH-60A to operate over long distances with auxiliary fuel by externally mounting a 450 gallon and a 230 gallon fuel tank on each side of the helicopter. Artificial and natural icing tests were required to qualify this configuration for flight in moderate icing.

b. The objective of this test was to conduct limited artificial and natural icing flight tests to provide AVSCOM the basis for establishing a moderate icing envelope for a UH-60A configured with the ESSS.

c. The ESSS is a modification of the UH-60A helicopter, designed to provide the capability for performing extended range missions and self-deployment. The test aircraft, UH-60A USA S/N 79-23352, is a twin-turbine single main rotor helicopter capable of day or night operations in visual or instrument meteorological conditions (IMC). The main and tail rotors are both four-bladed with a capability of manual main rotor blade and tail rotor pylon folding. The deicing kit installed incorporates a main and tail rotor deicing system and an ice detection system, as well as anti-ice provisions for the main rotor droop stops, the pilot and copilot windshields, pitot-static tubes and their support struts, engines, and engine inlets. The ESSS for the UH-60A consists of airframe fixed provisions and external stores subsystems. The airframe fixed provisions include permanent structural modifications, attachment points, fuel and pneumatic lines, and electrical harnesses. The external stores subsystem is comprised of a horizontal stores support, two support struts, and two vertical stores pylons for each side of the aircraft. The pylons are designed to accommodate a 450 gallon fuel tank on the inboard station and a 230 gallon tank on the outboard station. All stores stations are designed to permit jettison of loads. The ESSS installed on the test aircraft was a prototype design fully capable of stores jettison and fuel transfer. An improved airspeed system was installed which consisted of reoriented pitot-static tubes and fairing around the base of these tubes. Selected mock-up components of a prototype Wire Strike Protection System (WSPS) were also installed on the test aircraft.

d. In-flight artificial and natural icing tests were conducted in the vicinity of Duluth, Minnesota, from 20 February to 29 March, 1984. A total of 18 icing flights were conducted totaling 38.3 hours. Seven artificial icing flights totaling 5.0 productive hours, and 11 natural icing flights, totaling 18.6 productive hours were conducted. The test aircraft was flown in three different configurations: fixed provisions (the normal utility configuration with ESSS mounting provisions enclosed by fairings); ESSS with two 230 gallon tanks mounted on the outboard store stations; and ESSS with four tanks mounted. Anti-ice and deice systems were operated continuously while in the icing environment. A summary of specific test conditions is presented in Appendix B-28. Instrumentation and special equipment are shown Appendix C-26.

e. Airframe Ice Accretion and Shedding Characteristics -

(1) The airframe ice accretion and shedding characteristics of the ESSS configured UH-60A helicopter were evaluated in three configurations: the fixed provisions only, the two (230 gallon) external fuel tank, and the four (two 230 gallon and two 450 gallon) external fuel tank configurations. The test aircraft was also configured with the improved airspeed system and a portion of a prototype WSPS. In-flight photographic documentation from a chase aircraft, as well as onboard photography were utilized. Ice formed on all stagnation areas and sharp protrusions from the airframe, ESSS and external fuel tanks. Two shortcomings were documented which were associated with the ESSS configured UH-60 helicopter as tested with the prototype WSPS and improved airspeed system installed. The probability of rotating component FOD, due to impact with shed ice particles, is increased with the installation of the WSPS. The probability of engine FOD, due to ice ingestion, is increased with the installation of the improved airspeed system pitot-static tube support strut fairings or wedges.

(2) The ice accretion and shedding characteristics of the improved airspeed system pitot-static tube mounts were evaluated. A fairing was installed around the base plate of the standard UH-60A pitot-static tube support as a result of the improved airspeed system modification. Although a few instances of natural ice accretion shedding were observed, no engine FOD was noted. An alternate metal wedge pitot-static strut installation was tested with similar results. The large ice accretion and l cation of the formation relative to the engine inlet combined to increase the probability of engine FOD.

(3) The ice accretion and shedding characteristics of the fixed provision fairings were evaluated. Artificial and natural icing condition flights were conducted with the aircraft configured with fixed provision fairings. All icing flights were conducted with the prototype wing root fairings except for two flights where the right prototype wing root fairings (smooth surface) were replaced with production wing root fairings (ribbed surface). Small ice accretions (approximately 1/2 inch thick) occurred on the wing root fairings and a larger buildup of ice (approximately three inches thick) on the outboard portions of the fixed provision fairings. The area directly in front of the engine inlet accumulated only a small quantity of ice, and no engine or aircraft damage was documented when these formations shed. The ice accretion and shedding characteristics of the fixed provisions fairings (combined with either the prototype or production wing root fairings) were satisfactory.

(4) The ice accretion and shedding characteristics of the UH-60A helicopter configured with an ESSS and external fuel tanks were evaluated. Thirteen of the eighteen icing flights were conducted with the ESSS wing and fuel tanks installed. Eleven flights were flown with four external fuel tanks installed and two were conducted with the two 230 gallon outboard tanks installed. The ESSS installed on the test aircraft was an operable external fuel system and fuel was transferred during icing condition flight with ice accretions on the tanks and supports. As much as four inches of ice was accreted on the stagnation regions of the horizontal and vertical supports, and the nose of the fuel tanks. Larger accretions (approximately six inches thick) were observed on the wing struts due to their higher catch efficiency. On several occasions, the aircraft descended below the freezing level and these ice formations were shed. These ice sheds were observed from the chase aircraft and documented on video tape. In all cases, the shed ice particles passed well

clear of rotating components. No evidence of aircraft damage due to shedding of these ice accretions were documented.

(5) The stores jettison capability of the wing pylon stores racks was evaluated. Ice accreted on the forward end of both the inboard and outboard stores jettison racks in the area between the external fuel tanks and the vertical pylon fairings. The manual release mechanism level must move forward approximately 1/2 inch for the outboard jettison rack to fully release. Static (rotors stopped on the ground) jettison tests were satisfactorily accomplished with ice accretions which restricted the motion of the manual release lever. The inboard vertical pylon jettison rack is of a different construction and has no components restricted by ice accretions. No other ice accretion or shedding characteristics were observed which should effect aircraft operation or stores jettison. The stores jettison capability with ice accretion on the ESSS vertical pylon jettison racks was unsatisfactory.

(6) Ice accretion and shedding characteristics of selected portions of a prototype WSPS were evaluated. Two upper wire cutters and several wire deflectors were installed. The test installation included only the components considered to have an icing hazard potential. Large ice accretions (as much as five inches in thickness) were observed both from the chase aircraft and as a residual ice formations after landing. On several occasions, observers reported large pieces of ice departing these components and striking various fixed and rotating components of the test aircraft. Ice from the upper wire cutter was seen striking the pitch change links of the main rotor blades and fragmenting into the main and tail rotors. The location of these components near the aircraft centerline and forward of the rotating components contribute to the potential for FOD. Following several flights, in which the ice was naturally shed from the WSPS components, main and/or tail rotor blade damage was noted on the post-flight inspection. One such FOD occurrence (flight 17, average OAT of -7.0°C, average LWC of 0.36 gm/m$^3$) resulted in dents to three main rotor blade lower skin surfaces. One dent (0.086 inches deep at approximately two-thirds span) was cause for blade rejection. Another dent found on the tail rotor red blade skin approached blade paddle replacement criteria. Lesser damage to other main and tail rotor blades and tip caps were documented throughout these tests. No damage to the main rotor pitch change links were noted.

DEICE SYSTEMS

1. Deicing systems allow ice to build up and then remove it after it is formed, either periodically or at the end of an encounter. Areas that lend themselves to deicing rather than anti-icing are main and tail rotor systems, certain weapon systems, and most aerodynamic surfaces.

2. The electrothermal cyclic deicing concept is most often used on rotor systems, e.g., the UH-60A and YAH-64. These systems incorporate electrical heaters imbedded in the rotor blade which are periodically energized to heat the blade surface to 32°F. Two methods that have been used are chordwise shedding and spanwise shedding. In spanwise shedding, the blade heaters are divided into segments spanwise; in chordwise shedding, the heating elements run spannwise from root to tip, and the blade heater is divided into chordwise segments. Watt densities can vary from 10 to 30 watts/in$^2$ depending upon the degree of protection required. Segments are alternately heated in order to keep power requirements low.

3. An advantage of the deiced system concept for rotors is that with proper control, only the leading edge needs to be protected. Nominally, this amounts to approximately ten percent of the upper chord and 20 percent of the lower chord. Artificial icing test allow for the quick determination of proper on/off times to prevent runback. In most cases, shedding occurs symmetrically with little associated vibrations. If erosion shields are added to the rotor blades, some degradation to the deice capability can be expected.

4. Another deice system that has been tested is the pneumatic boot concept. A deicer boot is applied to the leading edge of the blade and ice is removed through periodic expansion (inflation) of chordwise and spanwise tubes. On such a system, electrical power requirements are low.

5. The disadvantage of either deice system is that shed ice can impact and cause aircraft damage. On the CH-47 series helicopters, for example, ice shed from the forward blades impact and damage the aft blades. Other areas damaged on other aircraft have been the tail rotor system, anti collision lights, and the tailboom.

ANTI-ICE SYSTEMS

1. Anti-ice systems are designed to prevent the accretion of ice by maintaining surface temperatures above freezing. Those systems most often anti-ice are the engine and engine inlet, the windshield, and the pitot static airspeed system.

2. The method must often chosen for engine anti-icing is a bleed air system. Engine, as well as engine inlets, are protected for up to the severe 2.0 $gm/m^3$ to prevent loss of engine power, flame out, and engine damage. During preliminary design testing, icing tests are invaluable in determining system adequacy. These type of inlet tests are often conducted in an icing tunnel where test conditions can be closely controlled. Final flight testing follows and here the intent is primarily to see not only if inlet protection is adequate, but also to see if shed ice is ingested. Some problems were encountered during UH-60A tests where ice was ingested causing engine damage. In the case of the OV-1D and other aircraft, the inlet anti-icing system was found to be inadequate in moderate icing encounters.

3. In order to provide complete visibility at all times, aircraft cleared for icing flights have anti-iced windshields. These are generally electrically treated systems which have high watt density capable of operating in moderate icing conditions. Because of manufacturing procedures, the edges and frames of heated windshields cannot be adequately heated and ice accretes in these areas. Over temperature protection must be provided as well to prevent over heating.

4. Pitot static airspeed systems are anti-iced to insure accurate airspeed indications under all conditions. These are also electrically heated type systems and usually have high reliability.

5. Actual icing flight testing can pinpoint problems in other areas when anti-icing systems may be required. For example, testing revealed the need for heated droop stops, and antennas.

6. The great advantage of an anti-icing system is that ice is not permitted to form so there is no concern or damage to the aircraft due to shed ice. The disadvantage is that larger amounts of power are required for anti-icing.

## ICE ACCRETION AND SHEDDING CHARACTERISTICS

1. Two important considerations for flight in icing conditions are: first, the ice accretion characteristics; and second, the ice shedding characteristics of a particular aircraft. Both of these phenomena must be well documented in icing tests to assure that all possibilities have been investigated.

2. Ice accretion on engine inlets, rotor blades, windshields, and control surfaces are primary concerns. Ice accretion characteristics are often difficult to obtain in that, to be accurate, they must be obtained in flight. Ice accumulations were photographed and measured at the termination of each flight where ambient conditions allowed retention of ice during return to the airfield. Due to sublimation, the residual ice may not be an accurate indication of the size and shape of the ice that was actually accreted in the cloud. Therefore, inflight photography or video recording remains the best means of obtaining ice accretion characteristics. This information can be obtained from photographic or video cameras on the test aircraft or on the chase aircraft.

3. Ice shedding characteristics are important because of the potential damage and FOD that can result from shed ice. Photography or video is again the best method of obtaining ice shedding information. After each flight, the aircraft is inspected for damage. The aft rotor of tandem aircraft, e.g., CH-47C, were often damaged by ice shed from the forward rotor.

4. Test pilots have reported visual differences in the type of ice formed in natural conditions from that found behind the HISS. These differences were in shape and consistency, and generally not in the location where formed. A program was initiated to detail any differences consisting of an airfoil section array in which ice shapes could be photographed and measured.

## PERFORMANCE

1. Level flight performance data were obtained by establishing trim level flight before, during, and after ice accretion on the aircraft. From a comparison of data, the results of ice accretion on performance could be determined. Increases in indicated engine torque, up to 12 percent on the UH-60A, occurred after icing encounters. This percent torque increase occurs as the blade accretes ice from its original clean configuration and represents a 22 percent increase in power from the no ice condition. Torque continues to increase and decrease over the corresponding ice accretion and deice cycles. Torque rises occurred on aircraft with both protected and unprotected rotor blades. As ice buildup occurred, lift was degraded and more power was required. As the ice was shed, either by the actuation of the deice system or by self shedding, the torque dropped and the cycle was repeated.

2. Engine power loss occurred with the operation of anti-ice systems requiring the use of bleed air, namely engine and engine inlet anti-ice systems. As bleed air was routed to anti-ice systems, less was available to engine and resulting power loss occurred. Some decrease in total power loss was accomplished by using undulating bleed air valves which kept bleed airflow between minimum and maximum levels, rather than continuously at maximum airflow.

3. Some loss in autorotational rotor speed was evident after icing encounters, and occurred if accreted ice remained on the blade during autorotation. This loss resulted from alteration of the airfoil section with the resultant loss of maximum lift and increased drag. For all aircraft tested, although autorotational RPM decrease occurred, autorotational RPM's were within recommended operational range. In many cases, entry into autorotation resulted in a partial or total shed of accummulated ice.

## STABILITY AND CONTROL

Stability and control characteristics were qualitatively evaluated during artificial and natural icing tests. No apparent variations were noted, but since the extreme limits of the flight envelopes could not be examined, some changes in stability and control characteristics could occur at these extremes.

## VIBRATION

Aircraft vibration characteristics were evaluated during icing encounters. Vibrations occurred primarily as the blades went through a deice cycle and ice shed as the blades were heated. Both qualita tive pilot's comments, as well as quantitative vibration data, were obtained. The vibration Rating Scale shown in Table 2 was used to assess aircraft vibration levels during rotor blade ice sheds. In general, vibration levels were slightly higher with sheds from unheated rather than from heated blades. The reasons for this were that first ice accretion thicknesses tended to be greater and unsymmetrical shed causing higher vibration levels occurred from unheated blades.

Table 2. Vibration Rating Scale

| Degree of Vibration | Description[1] | Pilot Rating |
|---|---|---|
| No Vibration | | 0 |
| Slight | Not apparent to experienced aircrew fully occupied by their tasks, but noticeable if their attention is directed to it or if not otherwise occupied. | 1<br>2<br>3 |
| Moderate | Experienced aircrew are aware of the vibration but it does not affect their work, at least over a short period. | 4<br>5<br>6 |
| Severe | Vibration is immediately apparent to experienced aircrew even when fully occupied. Performance of primary task is affected or tasks can only be done with difficulty. | 7<br>8<br>9 |
| Intolerable | Sole preoccupation of aircrew is to reduce vibration level. | 10 |

[1]Based upon the Subjective Vibration Assessment Scale developed by the Aeroplane and Armament Experimental Establishment, Boscombe Down, England.

## CLOUD PARAMETER MEASUREMENT EQUIPMENT

1. From its earliest development, methods were taken to measure the HISS cloud characteristics and compare each to the properties of natural clouds. Most early attempts measured LWC that related these values to water flowrate, airspeed, and distance to the test aircraft. Other attempts were made to measure droplet size by the gelatin slide method and cloud particle spectrometers. These earlier measurements revealed large droplet diameters and led to the replacement of the AAE nozzles.

2. When sonic nozzles were installed, a droplet measuring technique using laser nephelometers was initiated. Three droplet sizing probes, each measuring a range of droplet diameters, were installed on a UH-1H aircraft. The range of these probes were 3 to 45 microns, 30 to 300 microns, and 140 to 2100 microns. Similar measurements were obtained in natural icing cloud formations. Results indicated that with the new nozzles, the HISS produced a cloud whose droplet diameters and distribution were a reasonably good simulation of a natural cloud.

3. These laser nephelometers were originally installed on a UH-1H aircraft, but later a JU-21A fixed wing aircraft was used to acquire cloud parameter data. This aircraft was equipped with the following equipment: a Particle Measuring System (PMS) forward scattering spectrometer probe (model FSSP-100), a PMS optical array cloud droplet spectrometer probe (model OAP-200X), Rosemount outside air temperature sensor and display, Cambridge model 137 chilled mirror dew point hygrometer and display, Leigh MK-10 ice detector unit with digital display, Cloud Technology Ice Detector Unit, and a Small Intelligent Icing Data Systems (SIIDS).

4. The SIIDS is a compact data acquisition system designed for icing studies. The following parameters are displayed on the SIIDS printer.

a. Calendar - year, month, day, hour, minute, second.
b. Pressure altitude (ft).
c. Airspeed (knots).
d. Outside air temperature (°C).
e. Dew point (°C).
f. Total liquid water content observed by the FSSP (gm/m$^3$).
g. Total liquid water content observed by both the FSSP and OAP (gm/m$^3$).
h. Median volumetric diameter (m).
i. Amount of liquid water content observed for each channel (total 30) of both probes (gm/m$^3$).

5. The ice detector measures liquid water content directly. The output from the laser nephelometers was used to calculate liquid water content also and could be compared to the ice detector valves. Since liquid water content varies as the cube of the diameter, any small error in mean diameter caused large errors in LWC. As a result, LWC determinations by ice detectors and laser nephelometers did not always show good agreement.

6. Since the JU-21A can calibrate the HISS cloud and obtain natural cloud parameter data just prior to the test aircraft immersion, it is not necessary for the test aircraft to be equipped with cloud parameter measuring equipment. Ice detectors are the only cloud measuring device required because they are handheld usually part of the aircraft's ice protection system, and they provide

real time values of LWC. Since solar radiation has an effect upon ice accretion characteristics, several attempts to measure its effects were made. Solar radiation measuring devices were placed on test aircraft but results were inconclusive. Ice crystal content devices were also installed on test aircraft but these results also proved inconclusive.

TEST AIRCRAFT INSTRUMENTATION

1. The test aircraft instrumentation required during the flight test program can be divided into two general areas. The first includes instrumentation to monitor structural loads, vibrations, and temperatures which measure the effect upon the aircraft from flight in icing conditions; the second includes instrumentation to measure the actual environmental icing conditions, and record ice accretion characteristics.

2. The primary objectives of an icing flight test program are to:

a. Determine the effects of ice accretion on structural characteristics and handling qualities.

b. Verify the satisfactory operation of the rotor blade deice system and other anti-ice systems.

c. Verify the ice detection and/or icing rate meter operation.

d. Establish aircraft immersion times up to the aircraft endurance times.

3. Instrumentation was installed to measure main and tail rotor blade loads, rotor blade surface temperatures, aircraft and engine performance, and electrical system parameters. Vibration measurements were made to determine if potential problems existed. A typical list of the parameters recorded during testing is listed in Appendix C-5. This table reflects those parameters measured on they UH-60A during early development.

4. On board photographic coverage is essential in documenting ice accretion characteristics of the aircraft, and more particularly, of the rotor system. Photography is essential since there is little or no residual ice remaining on the aircraft after landings. Although photography obtained from a chase aircraft is useful, on board photography or video is preferred. Cameras, either hub or fuselage mounted, that record rotor blade accretion and shedding characteristics provide the best continuous data. Stereo-photography can provide a means of obtaining qualitative values of ice thickness.

TEST METHODOLOGY AND REQUIREMENTS FOR ICING QUALIFICATION

1. Several seasons of icing tests have provided the experience necessary to establish certain test procedures. Icing testing was accomplished in two phases. The first phase, artificial icing, consisted of completing a matrix of temperatures (0 to -20°C) and liquid water contents (.25 to 0.1 gm/$m^3$), requiring 16 separate test points presented below in Table 3:

Table 3. Matrix of Icing Test Conditions

| Temperature °C | LWC gm/$m^3$ [1] | | | |
|---|---|---|---|---|
| | .25 | .5 | .75 | 1.0 |
| -5 | x | x | x | x |
| 10 | x | x | x | x |
| -15 | x | x | x | x |
| -20 | x | x | x | x |

[1] The x's denote test conditions for temperature and LWC combinations.

2. In general, artificial icing tests were performed prior to initiating any natural icing tests. Artificial exposure was broad enough to encompass the natural conditions expected before a natural flight into those conditions was made. Initial flights included a confirmation of the proper operation of the anti/deicing systems. Test conditions were approached incrementally starting with the lowest LWC and highest temperatures and working toward higher LWC and colder temperatures. Each test condition lasted 30 minutes or until some limit condition was reached. The maximum altitude for artificial testing was 10,000 ft AGL. The general test procedures followed were:

(a) A JU-21A aircraft completed a weather survey to find the altitude for the selected test ambient condition.

(b) A preflight briefing was held for the test crew, HISS tanker crew, and rescue helicopter crew.

(c) Upon arriving at the test area, the HISS tanker stabilized at the altitude required for the selected temperature and began the water flow required to obtain the required LWC.

(d) The test aircraft took a data record in trimmed level flight before entering the HISS cloud.

(e) The test aircraft then entered the icing cloud behind the HISS and stabilized at approximately 100 KCAS at a distance of 150 ft behind the tanker. The distance is maintained by monitoring a set of lights in the rear of the HISS that receive input from a rearward facing radar altimeter also located in the HISS.

(f) After remaining in the cloud for approximately 30 minutes, the test aircraft exited and again recorded data in trimmed level flight. Photo documentation from both on board cameras and from cameras in the chase aircraft were obtained at this time.

3. Natural icing flight tests were performed for the primary purpose of validating the results obtained during the artificial phase of testing. The duration of testing was determined on the degree of agreement between the natural and artificial results. A JU-21A aircraft, equipped with cloud measuring devices or nephelometers, located and documented the natural icing conditions. The test aircraft, under instrument flight rules (IFR) was directed to the test area and tests were conducted in IMC icing conditions. Photographic documentation was provided by the JU-21A aircraft. Time in the clouds was limited by the availability of the natural icing conditions and aircraft IFR fuel requirements.

## REQUIREMENTS FOR OPERATIONAL AIRCRAFT FOR FLIGHT INTO ICING CONDITIONS

1. Aircraft with extensive ice protection systems installed, e.g., the UH-60A, were designed with a specific capability for flight in icing conditions. In the case of the UH-60A, this capability extended to the moderate level of icing intensity. Systems on the aircraft were designed, tested and qualified for this requirement. The icing criteria were presented in Figure 12 of USAAMRDL-TR-75-34A. Aircraft certification and qualification were established on the basis of many artificial and natural icing test flights. The aircraft is equipped with an OAT gauge and ice detector to warn the pilot should he encounter icing conditions exceeding the moderate level, i.e., 1.0 gm/m$^3$. If these conditions are encountered, the pilot is required to exit the environment, by either climbing or descending through the icing cloud, as quickly as possible.

2. Aircraft without ice protection systems, or with only partial ice protection systems, present a different certification or qualification problem. The U.S. Army has tested almost every aircraft within its inventory in the icing environment. Some aircraft such as the UH-1H and CH-47C/D have been tested extensively. The intent of testing was to determine if a safe operational icing envelope could be established. For many aircraft, a major problem lay in the original aircraft design requirements. Few aircraft had been designed for icing encounters and very little component qualification had been conducted. Generally the engine, engine inlets, and pitot system were the only areas with ice protection. Only a few aircraft of these earlier designs had windshield ice protection. Nevertheless, icing tests were initiated in order to establish a minimum, safe capability. Prototype rotor blade deice systems, ice phobic coatings and pneumatic boots were evaluated. Generally, icing tests revealed that every aircraft had some capability for flight into light icing conditions, none were considered to be adequately protected for moderate icing encounters. Since exposure to even light icing conditions led to assymetric sheds and unacceptable vibrations, a precise light icing envelope in terms of LWC, OAT, and time in cloud was difficult to establish. The best compromise, based upon testing, was not to restrict operation of the UH-1H, and CH-47C/D in light icing conditions, but to state that continuous operation in light icing conditions was not recommended. Testing further pointed out the need for reliable ice detectors on aircraft with limited icing capability. To date, ice detectors are not installed on UH-1H or CH-47C/D aircraft. Operators of these aircraft must rely upon weather forecasting and/or pilot comments for icing information.

3. Generally, fixed wing aircraft such as the OV-1D and U-21 exhibit a capability slightly better than the UH-1H and CH-47C/D. Testing has established that these aircraft are not adequately protected for safe continuous operation through moderate icing.

## CONCLUSIONS

1. U.S. Army icing criteria contained in USAAMRDL TR-75-34A, representing the 99.0 percentile level, are adequate for designing aircraft ice protection systems and for icing certification and qualification testing.

2. The HISS can be used for the testing of research and developmental ice protection systems and for the qualification of aircraft for flight in icing conditions.

3. Natural icing flights are still required for qualification because the HISS cannot precisely duplicate natural conditions in terms of water droplet size and droplet distribution or provide complete immersion of the test aircraft.

4. The HISS has the advantage of providing for safe, build-up type testing and also for testing at higher LWC's which are difficult to find in the natural environment.

5. Qualification of an aircraft for a partial icing envelope, e.g., up to moderate icing, is realistic provided the aircraft has an ice detection system which can warn the pilot of more severe conditions.

6. Aircraft deice systems have the disadvantage of causing potential aircraft damage when accreted ice is eventually shed.

7. HISS testing on low humidity days results in higher evaporation rates and fewer small water droplets.

8. The effects of solar radiation and sublimation can be reduced if HISS testing is conducted on cloudy, overcast days.

9. Use of the JU-21A and its associated cloud parameter measuring equipment is preferable to carrying similar devices on the test aircraft.

10. Because of the difference in ice shapes, it is important to test at temperatures near freezing, as well as at cold down to 20°C.

## RECOMMENDATIONS

1. The HISS Improvement Program should continue with the purpose of meeting the FAA goals for artificial cloud generation.

2. Helicopter Icing Criteria maximum levels of 2.0 $gm/m^3$ for severe icing should be reviewed to determine if this value is too excessive.

3. Stereo-photography and TV monitoring should be utilized in testing to obtain accurate details of ice accretion and shedding characteristics.

4. Ice phobic coating investigations and testing should continue, since this concept still has the potential for an inexpensive ice protection capability.

5. Weather forecasting methods need improvement and icing conditions need to be defined in terms of liquid water content and outside air temperature.

6. Future Army aircraft should be designed for operation in moderate icing conditions as a minimum, preferably for operation in severe icing conditions.

# APPENDIX A

# REFERENCES

## APPENDIX A. REFERENCES


A-1 Werner, J. B.; "The Development of an Advanced Anti-icing/Deicing Capability for U.S. Army Helicopters, Volume I - Design Criteria and Technology Considerations"; USAAMRDL-TR-75-34A, Nov 75.

A-2 Altobelli, J.; "Helicopter Icing Spray System (HISS) Improvement Program, Phase III Report," Boeing Vertol Report No. D145-10126-1, Mar 84.

A-3 DOT/FAA/CT-83/22.

A-4 DOT/FAA/CT-83-21 (NRL Report 8738)

A-5 "Certification of Transport Category Rotorcraft," FAA Advisory Circular 29-2, May 83.

A-6 Benson, Thomas, Woratschek, Stewart; "Icing Evaluation, U-21A Airplane with Low Reflective Paint"; USAAEFA Rpt. No. 77-05, May 77.

A-7 Mittag, O'Connor, Hanks, Kronenberger; "Artificial Icing Tests, CH-47C Helicopter"; USAAEFA Rpt. No. 73-04-1, Aug 74.

A-8 Niemann, Spring, Bowers; "Artificial Icing Test CH-47C Helicopter with Fiberglass Rotor Blades"; USAAEFA Rpt. No. 78-18, Jul 79.

A-9 Adams, Bowers, Abbott; "YCH-47D Natural and Simulated Icing"; USAAEFA Rpt. No. 79-07, Jul 81.

A-10 Gilmore, Robbins; "Limited Artificial Icing Tests of the OV-1D"; USAAEFA Report No. 80-16, Jul 81.

A-11 Carpenter, Ward, Robbins, "Limited Artificial and Natrual Icing Test of the OV-1D (Re-Evaluation)"; USAAEFA Rpt. No. 81-21, Aug 82.

A-12 Buckanin, Tulloch; "Artificial Icing Tests Utility Tactical Transport Aircraft System (UTTAS) Sikorsky YUH-60A Helicopter"; USAAEFA Rpt. No. 76-09-1, Feb 77.

A-13 Tulloch, Mullen, Belte; "Artificial and Natural Icing Tests, Production UH-60A Helicopter"; USAAEFA Rpt. No. 78-05, Oct 79.

A-14 Hanks, Higgins, Dieckman; "UH-60A Natural and Simulated Icing"; USAAEFA Rpt. No. 79-19, Jun 80.

A-15 Hanks, Dieckmann, Benson; "Limited Artificial and Natural Icing Tests Production UH-60A Helicopter (Reevaluation)"; USAAEFA Rpt. No. 80-14, Aug 81.

A-16 Hagen, O'Connor, Tavares; "Artificial Icing Test Utility Tactical Transport Aircraft System (UTTAS) Boeing Vertol YUH-61A Helicopter"; USAAEFA Rpt. No. 76-09-2, Jan 77.

A-17 Smith, Mittag, Hanks, Reid; "Artificial Icing Tests, AH-1G Helicopter"; USAAEFA Rpt. No.73-04-2, Nov 74.

A-18 Ward; "Support of Bell Helicopter Textron Icing Certification Effort of the 214ST Helicopter"; USAAEFA Rpt. No. 81-13, Apr 82.

A-19 "Letter of Effort, YAH-64 Icing Survey"; USAAEFA Rpt. No. 80-08.

A-20 Hanks, Reid, Merrill; "Artificial Icing Tests AH-1Q Helicopter (U)"; USAAEFA Rpt. No. 73-04-7, Jan 74.

A-21 Ward; "Support of United Technologies Corp., Sikorsky Aricraft Division, Icing Certification Effort of the S-76 Helicopter"; USAAEFA Rpt. No. 81-15, Apr 85.

A-22 Ward; "Helicopter Icing Spray System (HISS) Support for Bell Helicopter Textron (BHT) Model 412 Helicopter"; USAAEFA Rpt No. 80-10.

A-23 Griffith, Smith, Reid, Brewer, Hanks; "Artificial Icing Tests UH-1H Helicopter, Part I"; USAAEFA Rpt. No. 73-04-4, Jan 74.

A-24 Griffith, Mittag, Hanks, Hawley; "Artificial Icing Tests UH-1H Helicopter, Part II Heated Glass Windshield"; USAAEFA Rpt. No. 73-04-4, Jan 74.

A-25 Griffith, Mittag, Hanks, Reid; "Natural Icing Tests, UH-1H Helicopter"; USAAEFA Rpt. No. 74-31, Jun 74.

A-26 Kronenberger, Merrill, Hanks; "Artificial Icing Tests, Lockheed Advanced Ice Protection System Installed on a UH-1H Helicopter"; USAAEFA Rpt. No. 74-13, Jun 75.

A-27 Kronenberger; "Lockheed Advanced Ice Protection System Test"; USAAEFA Rpt. No. 75-26/76-04, Mar 76.

A-28 Tulloch, Doten, Smith, Bishop; "Artificial Icing Test, Ice Phobic Coatings on UH-1H Helicopter Rotor Blades"; USAAEFA Rpt. No. 77-30, Jun 78.

A-29 Wilson, Woratschek; "Artificial and Natural Icing Tests for Qualification of UH-1H Kit A Aircraft"; USAAEFA Rpt. No. 78-21, Aug 79.

A-30 Wilson, Woratschek; "Microphysical Properties of Artificial and Natural Clouds and Their Effects on UH-1H Helicopter Icing"; USAAEFA Rpt. No. 78-21-2, Aug 79.

A-31 Morris, Woratschek; "UH-1H Ice Phobic Coatings and Calibration of Modified HISS"; USAAEFA Rpt. No. 79-02, Jul 80.

A-32 Henderson, Woratschek, Haworth; "HISS Calibration, Ice Phobics and R&D Evaluations"; USAAEFA Rpt. No. 80-13, Aug 81.

A-33 Haworth, Oliver, Woratschek; "JUH-1H Pneumatic Boot Deicing System Flight Test Evaluation"; USAAEFA Rpt. No. 81-11, May 83.

A-34 Abbott, Belte, Williams, Stellar; "Evaluation of UH-1H Hover Performance Caused by Rotor Icing"; USAAEFA Rpt. No. 82-12, Aug 83.

A-35 Abbott, Linehan, Lockwood, Todd; "Evaluation of UH-1H Level Flight Performance Degradation Caused by Rotor Icing"; USAAEFA Rpt. No. 83-23, Jul 84.

A-36 Robbins. Dieckmann; "UH-60A Light Icing Envelope Evaluation with the Blade Deicing Kit Installed but Inoperative"; USAAEFA Rpt. No. 81-18, Jun 82.

A-37 Tavares, Sullivan, Hanks, Woratschek; "Artificial and Natural Icing Tests YEH-60A Quick Fix Helicopter"; USAAEFA Rpt. No. 83-21.

A-38 Hanks, Woratschek; "Limited Artificial and Natural Icing Tests of the External Stores Support System (ESSS) Installed on a UH-60A Aircraft"; USAAEFA Rpt. No. 83-22, Jun 84.

## APPENDIX B. TEST CONDITIONS

The following tables list the test conditions for the aircraft listed in Table 1 below. Not all test projects have an appendix listing test condition due to a lack of availability of information.

Table 1 Test Conditions

| Appendix | Aircraft | USAAEFA Project Number |
|---|---|---|
| B-1 | CH-47C | 73-04-1 |
| B-2 | CH-47C | 78-18 |
| B-3 | YCH-47D | 79-07 |
| B-4 | OV-1D | 80-16 |
| B-5 | OV-1D | 81-21 |
| B-6 | YUH-60 | 76-09-1 |
| B-7 | UH-60A | 78-05 |
| B-8 | UH-60A | 79-19 |
| B-9 | UH-60A | 80-14 |
| B-10 | YUH-61 | 76-09-2 |
| B-11 | AH-1G | 73-04-2 |
| B-12 | Bell 214ST | 81-13 |
| B-13a | YAH-64 | 80-08 |
| B-13b | YAH-64 | 80-08 |
| B-14 | UH-1H | 73-04-4 Part I |
| B-15 | UH-1H | 72-04-4 Part II |
| B-16 | UH-1H | 74-31 |
| B-17 | UH-1H | 74-13 |
| B-18 | UH-1H | 75-26 |
| B-19 | UH-1H | 77-30 |
| B-20 | UH-1H | 78-21 & 78-21-2 |
| B-21 | UH-1H | 79-02 |
| B-22 | UH-1H | 80-13 |
| B-23 | JUH-1H | 81-11 |
| B-24 | UH-1H | 82-12 |
| B-25 | UH-1H | 83-23 |
| B-26 | UH-60A | 81-18 |
| B-27 | YEH-60A | 83-21 |
| B-28 | UH-60A | 83-22 |

# APPENDIX B-1
# CH-47C (Project No. 73-04-1)

## Specific Test Conditions

| Flight Number | Programmed Icing Severity | Average Static Temperature (°C) | Programmed Liquid Water Content (gram/meter$^3$) | Time in Icing Condition (min) | Component Iced | Average Density Altitude (ft) | Average True Airspeed (kt) |
|---|---|---|---|---|---|---|---|
| 1 | Light | -6.0 | 0.25 | 5<br>10<br>15 | Fwd rotor<br>Fwd rotor<br>Aft rotor | 4960 | 95 |
| 2 | Heavy | -6.5 | 1.05[2] | 10<br>4.5[3] | Fwd rotor<br>Aft rotor | 5480 | 33 |
| 3 | Light | -6.5 | 0.25 | 30<br>21 | Fwd rotor<br>Aft rotor | 7380 | 102 |
| 4 | Light | -8.5 | 0.25 | 10<br>5<br>26<br>9 | Fwd rotor<br>Aft rotor<br>Fwd rotor<br>Fwd rotor | 10380 | 96 |
| 5 | Moderate | -8.5 | 0.50 | 11<br>15 | Fwd rotor<br>Fwd rotor | 10840 | 98 |

NOTES: [1] Average center of gravity (cg) location: 333.2 inches
Rotor speed: 235 rpm
Average gross weight: 28,200 pounds

[2] Estimated value. Flowmeter on spray system malfunctioned.
[3] Icing terminated. Spray system water depleted.

C86-TH48

# APPENDIX B-2
## CH-47C (Project No. 78-18)
### Specific Test Conditions[1]

| Flight | Date 1979 | Average Pressure Altitude (ft) | Average OAT (°C) | LWC (gm/m³) | Relative Humidity (%) | Deice Cycles | Time in Cloud (min) | Time[2] to First Detect (min) | Max Ice[4] Buildup (in.) | Average Ice[3] Accretion (15 min) (in.) | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2/1 | 2500 | -16 | 0.25 | 65-85 | 12 | 60 | 25 | 1/4 | Not Available | $V_H$ + 15; blade deice ON time increased (+1.5 sec) after flight |
| 2 | 2/10 | 4700 | -13 | 0.25 | 75 | 6 | 60 | 36 | 1/4 | Not Available | |
| 3 | 2/12 | 4000 | -10 | 0.50 | 10 | 14 | 36 | 4 | 1/2 | 0.76 | Blade deice ON time increased (+1.5 sec) after flight; aircraft cold soaked for 30 min prior to flight |
| 4 | 2/13 | 4600 | -11 | 0.25 | 80-95 | 5 | 33 | 0 | 1/4 | 0.54 | |
| 6 | 2/19 | 8400 | -5 | 0.50 | 60 | 14 | 40 | 2 | 3/8 | Not Available | Small identation found on forward head prior to Flight 7 |
| 7 | 2/19 | 9500 | -5 | 0.75 | 40 | 14 | 28 | 2 | 3/8 | 0.5 | #1 engine anti-ice OFF |

NOTES: [1] Clean configuration with rotor speed 225 rpm; mid cg. All flights were behind the HISS. Engine start gross weight, 32,300 lbs; true airspeed, 90 knots.
[2] Time until the first deice cycle of one of the three detectors.
[3] Determined using data recorded from the three detectors.
[4] The maximum thickness of ice usually measured on the OAT probe on the aircraft after flight.

C86-TH49

# APPENDIX B-3
# YCH-47D (Project No. 79-07)

## Specific Test Conditions

Heated Phase Rotor Blade Tests[1]

| Flt | Date 1980 | Average Pressure Altitude (ft) | Average OAT (°C) | Peak Indicated LWC[2] (gm/m³) | LWC From HISS Calibration (gm/m³) | HISS Flow Rate[3] (gal/min) | Relative Humidity (pct) | Deice Cycles | Immersion Times (min) Fwd Rotor | Immersion Times (min) Aft Rotor | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 14 Feb | 2150 | -12 | 0.35 | 0.4 | 7 | 77 | 6 | 26 | 31 | ESGW 34,030 lb |
| 2 | 15 Feb | 1600 | -13 | 0.54 | 0.5 | 10 | 86 | 8 | 33 | [illegible] | ESGW 47,300 lb |
| 3 | 16 Feb | 3040 | -20 | 0.50 | 0.5 | 10 | 90 | 7 | <u>35</u> | <u>39</u> | ESGW 47,700 lb |
| | | | | | [illegible] in cloud | 1.6 hr | 1.4 hr | | | | |

NOTES: [1] Artificial cloud; clear [illegible] speed 225 rpm; average airspeed 90 KTAS
[2] Liquid water conte[illegible] [illegible]eigh Mark XII Ice Detector.
[3] Indicated flow rate

C86-TH50

# APPENDIX B-4
# OV-1D (Project 80-16)

## Artificial Icing Test Points
## LIQUID WATER CONTENT—LWC
## (grams/meter$^3$—gm/m$^3$)

| AMBIENT TEMPERATURE (Degrees Centigrade-°C) | 0.25 | 0.5 | 0.75 | 1.0 |
|---|---|---|---|---|
| -5 | | X | X | X |
| -10 | | X | X | |
| -15 | X | X | | |
| -20 | X | X | | |

C86-TH51

# APPENDIX B-5
## OV-1D (Project No. 81-21)
### Specific Test Conditions

| Flight Number | Temperature (°C) | Average Liquid Water Content ($g/m^3$) | Median Volumetric Diameter (microns) | Relative Humidity (percent) | Time in Cloud (hour) | Remarks |
|---|---|---|---|---|---|---|
| 1 | -20 | .48 | 29 | 67 | 0.6 | 7.5 KVA gen installed |
| 2 | -19.5 | .59 | 25 | 56 | 0.3 | abort for HISS |
| 3 | -4 | .98 | 78 | 88 | 0.8 | |

C86-TH52

# APPENDIX B-6
# YUH-60 (Project No. 76-09-1)

## Specific Test Conditions[1]

| Flight Number | Average Gross Weight[3] (lb) | Average Center of Gravity Location 4,5 (in.) | Average Density Altitude (ft) | Total Time in Cloud (min) | Average Static Outside Air Temperature (°C) | Programmed Liquid Water Content ($gm/m^3$) |
|---|---|---|---|---|---|---|
| 2 | 15,600 | 352.7 | 340 | 5 | 11.0 | .25 |
| 3 | 15,700 | 353.1 | 2880 | 10 | -5.5 | .25 |
| 5 | 16,460 | 356.3 | 5180 | — | -5.5 | — |
| 6 | 15,900 | 353.9 | 5380 | 16 | -5.5 | .25 |
| 13 | 15,560 | 357.2 | 450 | 8 | -10.5 | .25 |
| 14 | 14,860 | 354.1 | 1140 | 53 | -12.0 | .25 |
| 15 | 15,180 | 355.4 | 720 | 4 | -12.0 | .50 |
| 16 | 14,980 | 354.7 | -1060 | 16 | -15.5 | .25 |
| 17 | 15,180 | 355.4 | -820 | 34 | -11.0 | .50 |
| 18 | 15,420 | 355.5 | 9100 | — | -15.0 | — |
| 19 | 15,440 | 356.7 | -540 | 42 | -16.0 | .25 |

NOTES: [1] Configuration: Normal utility; rotor speed: 258 rpm; airspeed in icing cloud: 90 KTAS
[2] Nonicing flights not presented
[3] Average gross weight excluding accreted ice
[4] All longitudinal cg locations were near mid range and excluded the effect of accreted ice
[5] Average lateral cg: 0.1 inch right

C86-TH53

# APPENDIX B-7
## UH-60A (Project No. 78-05)

### Specific Test Conditions[1]

| Average Pressure Altitude (ft) | Average Static Outside Air Temperature (°C) | Average Relative Humidity (%) | Programmed Liquid Water Content (gm/m³) | Number of Cloud Immersions | Total Cloud Immersion Time (min) | Remarks |
|---|---|---|---|---|---|---|
| 10,000 | -5 | — | 0.5 | 1 | 10 | Initial Checkout |
| 6,800 | -10 | 4 | 0.5 | 3 | 31.5 | Required Checkout |
| 4,000 | -5 | 45 | 0.75 | 2 | 27.5 | Required Point |
| 4,000 | -5 | 62 | 0.15<br>0.25<br>0.5<br>0.75 | 1 | 4<br>13<br>4<br>3 | Qualitative Assessment |
| 4,700 | -5 | 77 | 0.5 | 1 | 43 | First Army Flight |

NOTE: [1] Configuration: Normal utility; takeoff gross weight: 16,860 pounds, takeoff longitudinal center of gravity fuselage station: 360.2; 258 main rotor rpm; airspeed in icing cloud: 90 KTAS.

C86-TH54

# APPENDIX B-3
## UH-60A (Project No. 79-19)
### Specific Test Conditions[1]

| Number of Flights | Environment | Configuration | Average Static Outside Air Temperature (°C) | Average Liquid Water Content (gm/m³) | True Airspeed (KTAS) | Time in Cloud (hrs) | Time Flight Time (hrs) |
|---|---|---|---|---|---|---|---|
| 4 | Artificial Icing | IR Suppressed[2] | -3 to 21.5 | 0.25 to 1.0 | 82 | 3.7 | 6.9 |
| 3 | Natural Icing | IR Suppressed | -7 to -12 | 0.09 to 0.24 | 120 | 3.1 | 6.0 |
| 11 | Natural Icing | Clean[3] | -4 to -11 | 0.01 to 0.32 | 93 to 138 | 17.4 | 24.5 |
| 12 | Non-Icing | IR Suppressed Clean | N/A | N/A | N/A | 3.6[4] | 14.8 |

NOTES: [1] Main rotor speed: 258 rpm
Average gross weight: 16,320 lb
Average center of gravity: longitudinal: FS354.3 in: lateral: BL0.3 in. left
[2] IR Suppressor, ALQ-144 IR Countermeasures Device, M-130 Chaff Dispenser
[3] Standard Tailpipes, M-130 Chaff Dispenser
[4] Productive flight time in VMC conditions

D86-TH55A

# APPENDIX B-9
# UH-60A (Project No. 80-14)

## Specific Test Conditions

| Flight Number | Environment | Average Gross Weight (lb) | Average Long. CG (FS) | Average Density Altitude (ft) | Average FAT (°C) | Average[1] Rosemount Indicated LWC ($gm/m^3$) | Maximum[1] Rosemount Indicated LWC ($gm/m^3$) | Average TAS (KTAS) | Total Time In Cloud (min) | Ice Accreted On Visual Probe (in.) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Artificial | 1[illegible],700 | 352.7 | 2740 | -7.0 | 1.00 | 1.00 | 118 | 50 | N/A[2] |
| 2 | Artificial | 1[illegible],750 | 353.0 | 3540 | -7.5 | 1.00 | 1.00 | 120 | 50 | N/A |
| 5 | Artificial | 1[illegible],500 | 352.0 | 4140 | -15.0 | 0.60 | 0.60 | 122 | 78 | N/A |
| 6 | Artificial | 1[illegible],600 | 352.3 | 1400 | -15.0 | 0.60 | 0.50 | 117 | [illegible] | N/A |
| 8 | Artificial | 1[illegible],040 | 354.[illegible] | 7730 | -6.0 | 1.00[3] | 1.00[3] | 122 | 50 | N/A |
| 9 | Natural | 1[illegible],940 | 353.6 | 2640 | -6.0 | 0.34 | 0.78 | 141 | 114 | 2.5 |
| 10 | Artificial | 1[illegible],500 | 351.7 | -1500 | -20.0 | 0.25[3] | 0.25[3] | 116 | 66 | N/A |
| [illegible] | Artificial | 1[illegible],500 | 351.8 | 3920 | 13.0 | 0.75[3] | 0.75[3] | 114 | 72 | N/A |
| 12 | Natural | 1[illegible],800 | 353.0 | 2400 | -9.0 | 0.44 | 0.54 | 128 | 96 | 4.0 |
| 13 | Natural | 1[illegible],760 | 352.8 | 2480 | -9.5 | 0.29 | 0.33 | 106 | 108 | 3.5 |
| [illegible] | Artificial | 1[illegible],200 | 354.6 | -100 | -22.0 | 0.25[3] | 0.25[3] | 120 | 72 | N/A |
| 16 | Artificial | 1[illegible],100 | 354.1 | -560 | -21.5 | 0.75[3] | 0.75[3] | 111 | 72 | N/A |
| 17 | Artificial | 1[illegible],740 | 352.9 | 1560 | -10.0 | 1.00 | 1.00 | 116 | 60 | N/A |
| 18 | Artificial | 1[illegible],660 | 352.6 | 2460 | -13.0 | 1.00 | 1.00 | 118 | 48 | N/A |
| 19 | Artificial | 1[illegible],360 | 355.2 | -460 | -19.0 | 1.00 | 1.00 | 115 | 24 | N/A |
| 21 | Artificial | 1[illegible],100 | 354.2 | 4360 | -7.0 | 1.00[3] | 1.00[3] | 118 | 48 | N/A |
| 22 | Artificial | 1[illegible],140 | 354.3 | 6880 | -7.0 | -[4] | -[4] | 90<br>119 | 20<br>20 | N/A |

NOTES: [1] Programmed LWC indicated for artificial icing flights.
[2] Location of the visual probe precluded it from exposure to the spray cloud during artificial icing.
[3] Additionally, sweeps of the HISS cloud at 0.25, 0.50, 0.75, and 1.00 $gm/m^3$ LWC were accomplished on these flights.
[4] Sweeps of the HISS cloud at 0.25, 0.50, 0.75, and 1.00 $gm/m^3$ LWC were accomplished on these flights.

D86-TH56A

# APPENDIX B-10
## YUH-61 (Project No. 76-09-2)

### Specific Test Conditions

| Flight Number | Average Static Outside Air Temperature (°C) | Programmed Liquid Water Content (gm/m³) | Time In Icing Condition (min) | Average Density Altitude (ft) | Average True Airspeed (kt) | Average Gross Weight[3] (lb) | Average Center of Gravity[3] (in.) |
|---|---|---|---|---|---|---|---|
| 2[4] | -6.5 | 0.25 | 7 | 1590 | 86 | 15,860 | 205.6 |
| 4 | -11.5 | 0.25 | 10 | 80 | 88 | 15,860 | 206.8 |
| 5 | -6.5 | 0.50 | 22 | 2940 | 84 | 15,800 | 206.5 |
| 6 | -11.0 | 0.25 | 39 | 6680 | 91 | 15,760 | 206.3 |
| 7 | -6.0 | 0.75 | 13 | 6140 | 92 | 15,740 | 206.2 |
| 9 | -16.0 | 0.25 | 48 | -1100 | 91 | 15,640 | 205.8 |
| 10 | -13.0 | 0.50 | 29 | 1560 | 89 | 15,720 | 206.2 |
| 11[5] | -12.5 | 0.25 | 6 | -100 | 91 | 15,980 | 207.3 |
| 12[5] | -13.5 | 0.25 | 18 | -400 | 90 | 15,860 | 206.8 |

NOTES: [1] Normal utility configuration. Rotor speed: 286 rpm (100 percent)
[2] Non-icing flights are not presented.
[3] Average values excluding effects of accreted ice
[4] Deice system ice detector malfunction
[5] Unheated phase. Main rotor, tail rotor, and horizontal stabilizer deicer OFF

D86-TH57A

# APPENDIX B-11
# AH-1G (Project No. 73-04-2)

## Specific Test Conditions

| Flight Number | Average Static Air Temperature (°C) | Programmed Liquid Water Content[2] ($g/m^3$) | Average Density Altitude (ft) | Average True Airspeed (kt) | Average Gross Weight (lb) | Average Center-of-Gravity Location (in.) | Time in Cloud (min) | Major Component Iced | Configuration |
|---|---|---|---|---|---|---|---|---|---|
| 1 | -5.0 | 0.25 (L)[3] | 2200 | 90 | 8300 | 199.4 | 10 | Main rotor | External stores |
| 2 | -5.0 | 0.50 (M)[4] | 4500 | [illegible] | 8250 | 199.4 | 20 | Fuselage | External stores |
| 3 | -5.0 | 0.50 (M) | 6400 | 103 | 8200 | 199.4 | 15 | Main rotor | External stores |
| 4 | -4.5 | 0.50 (M) | 6700 | 103 | 8200 | 199.4 | 13 | Main rotor | External stores |
| 5 | -9.0 | 0.25 (L) | 8000 | 105 | 8300 | 199.4 | 15 | Main rotor | External stores |
| 6 | -4.5 | 0.50 (M) | 5600 | 102 | 7800 | 197.9 | 20 | Fuselage | Clean |
| 7 | -9.0 | 0.25 (L) | 800 | 95 | 7200 | 197.6 | 10 | Main rotor | Clean |
| 8 | -5.5 | 0.75 (M) | 6000 | 94 | 7700 | 195.6 | 0.5 | Fuselage | Clean |
| 9 | -5.0 | 0.25 (L) | 9500 | 102 | 7800 | 199.2 | 30 | Fuselage and main rotor | Clean |
| 10 | -6.0 | 0.25 (L) | 7800 | 100 | 7900 | 200.0 | 35 | Fuselage and main rotor | IR[5] |
| 11 | -6.0 | 0.25 (L) | 7000 | 102 | 7700 | 200.0 | 25 | Fuselage and main rotor | IR |
| 12 | -10.0 | 0.25 (L) | 8800 | 105 | 8000 | 199.8 | 15 | Main rotor | IR |
| 13 | -9.0 | 0.50 (M) | 9300 | 92 | 8100 | 199.5 | 0.5 | Main rotor | IR |
| 14 | -13.0 | 0.25 (L) | 9500 | 92 | 7900 | 200.0 | 13 | Main rotor | IR |
| 15 | -13.0 | 0.25 (L) | 9300 | 91 | 8000 | 200.0 | 15 | Main rotor | IR |
| 16 | -11.0 | 0.50 (M) | 6400 | 90 | 7300 | 199.8 | 4 | Main rotor | IR |

NOTES: [1] Rotor speed: 324 rpm.
[2] Refer to page 2, para 3, introduction for icing severity level definitions.
[3] L: Light.
[4] M: Moderate.
[5] Infrared suppressor system installed.

C86-TH64

# APPENDIX B-12
# BELL 214ST (Project No. 81 13)

## Specific Test Conditions[1]

| Flight Number | Temperature (Deg -C) | Liquid Water Content ($gm/m^3$) | Median Volumetric Diameter ( ) | Relative Humidity (%) | Cloud Time (hr) | Remarks |
|---|---|---|---|---|---|---|
| 1 | 13 | .24 | 35 | 24 | .8 | Rotor |
| 2 | 9.3/10.5 | .29/.45 | 24/27 | 83/82 | .5/.2 | Fuselage/Rotor abort 214 rotor |
| 3 | 9.5 | .57 | 26 | 87 | .5 | Rotor abort HISS water pump |
| 4 | 14.5/16.4 | .49/.44 | 25/27 | 78/67 | 1.0/.4 | Rotor |
| 5 | 15.0/14.5 | .55/.60 | 32/34 | 65 | .7/.4 | Rotor |
| 6 | 5.0 | .28 | 36 | 85 | .4 | Abort 214 tail rotor |
| 7 | 5.5/5.8 | .98/.52 | 62/50 | 38/32 | .3/.3 | Rotor/Fuselage |
| [illegible] | 10.1 | .3 | 41 | 30 | .7 | Rotor abort for HISS hose |
| 9 | 10.0 | .89 | 72 | 12 | .3 | Fuselage |

C86-TH58

# APPENDIX B-13a
# YAH-64 (Project No. 80-08)

## Specific Test Conditions

| Flight Number | Immersed Component | Takeoff Gross Weight (pounds) | Takeoff Long CG (inches) | Average Density Altitude (feet) | Average OAT (Deg C) | Average[1] Relative Humidity (percent) | Average[1] LWC (grams/cubic meter) | Median Volumetric Diameter (Microns) | Average True Airspeed (knots) | Total Time in Cloud (hour) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Rotors | 16280 | 205.5 | 4360 | -6.0 | 44 | 0.17 | 31 | 120 | 30 |
| 2 | Rotors | 16280 | 205.5 | 2600 | -11.0 | 85 | 0.25 | --[3] | 120 | 30 |
| | | | | 2600 | -11.0 | 85 | 0.51 | 25 | 120 | 30 |
| 3 | Rotors | 16660 | 205.1 | 1500 | -20.0 | 84 | 0.31 | 19 | 120 | 31 |
| | | | | 1000 | -20.0 | 84 | 0.50 | 27 | 120 | 33 |
| 4 | Rotors | 16600 | 205.1 | 1300 | -21.5 | 76 | 0.75 | 72 | 120 | 25 |
| | | | | 1300 | -21.5 | 76 | 1.10 | 72 | 120 | 29 |
| 5 | Fuselage | 16600 | 205.1 | 9800 | -6.0 | 67 | 0.50 | --[3] | 90 | 32 |
| | | | | 9800 | -6.0 | 67 | 0.75 | --[3] | 90 | 41 |
| 6 | Fuselage | 16700 | 205.0 | 6500 | -14.5 | 97 | 0.57 | --[3] | 120 | 30 |
| | | | | 6500 | -14.5 | 97 | 0.77 | --[3] | 120 | 27 |
| 7 | Rotors | 16760 | 205.0 | 1200 | -5.0 | 99 | 0.75 | --[3] | 120 | 29 |
| | | | | 1200 | -5.0 | 99 | 1.00 | --[3] | 120 | 31 |
| 8 | Fuselage | 16760 | 205.0 | 6400 | -10.0 | 70 | 0.75 | --[3] | 120 | 43 |
| 9 | Rotors | 16700 | 205.0 | 1560 | -13.0 | 30 | 0.77 | 55 | 120 | 27 |
| | | | | 1560 | -13.5 | 30 | 1.02 | 60 | 120 | 27 |
| 10 | Fuselage | 16700 | 205.0 | -400 | -12.5 | 77 | 1.19 | 41 | 120 | 61 |
| 11 | Rotors | 15960 | 204.8 | 5000 | -10.0 | 80 | 0.81 | 32 | 120 | 29 |
| | | | | 4900 | -10.0 | 80 | 1.06 | 48 | 120 | 7 |
| 12 | Fuselage | 16860 | 204.8 | 2000 | -16.8 | 58 | 1.02 | 28 | 120 | 46 |

NOTES: [1] Relative humidity, LWC, and MVD were measured by the JU-21A prior to the test aircraft immersion.
[2] De-ice system ON and OFF times were set manually.
[3] LWC data was estimated from HISS flow rate. MVD data not available.

C85 TH65

# APPENDIX B-13b
# YAH-64 (Project No. 80-08)

## Specific Test Conditions[1]

| Immersed Component | Number of Flights | OAT (DEG C) | Relative Humidity (Percent) | LWC (grams/cubic) meter | Median Volumetric Diameter (Microns) | Average True Airspeed (knots) | Total Time in Cloud (hours) |
|---|---|---|---|---|---|---|---|
| Rotor Systems | 7 | -5.0 to -21.5 | 30 to 99 | 0.17 to 1.1 | 19 to 72 | 120 | 5.8 |
| Fuselage | 5 | -6.0 to -16.0 | 58 to 97 | 0.5 to 1.06 | 28 to 41 | 90 & 120 | 4.7 |
| Clear Air Flt | 3 | -7.0 to -20.0 | N/A | N/A | N/A | N/A | 2.8[2] |

NOTES: [1] Average takeoff gross weight = 16,670 pounds
Average takeoff longitudinal cg FS 205.1 (aft)
Rotor speed = 289 rpm
[2] Productive flight time

D86-TH59A

# APPENDIXES B-14 thru B-22

# UH-1 (Project Nos. 73-04-4, 74-31, 74-13, 75-26, 77-30, 78-21, 79-02 and 80-13)

## General Test Conditions

| Project Number | Dates of Test | Location | Number of Flights | Productive Flight Hours | Gross Weight (lbs) | Longitudinal Center-of-Gravity Location (FS) | Density Altitude (ft) | Rotor Speed (rpm) | True Airspeed (kts) | Outside Air Temperature | Liquid Water Content (gm/m$^3$) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 73-04-4 Part I | 17 Sep - 29 Oct 73 | Ft. Wainwright, Alaska | 15 | 13.7 | 7400 | [illegible] (mid) | -160 to 9480 | 324 | 94 to 108 | -5.0 to -14.0 | 0.25 & 0.50[1] |
| 73-04-4 Part II | 3 Jan - 3 Jan 74 | Edwards AFB, California | 2 | [illegible] | 7200 | 143.0 (mid) | 6000[2] | 324 | 90[3] | -5.5 | moderate |
| 74-31 | 5 Feb - 23 Feb 74 | Ft. Lewis, Washington | 4 | 1.7 | 6800 to 6980 | [illegible] - 137.6 (mid) | 3380 to 5660[2] | 317 to 320 | 93 to 100 | -2.0 to -5.5 | trace to moderate |
| 74-13 | 10 Mar - 31 Mar 75 | Moses Lake, Washington | 9 | 9.9 | 7560 to 8080 | 136.3 - 138.3 (mid) | 2600 to 8980 | 324 | 80[3] | -4.5 to -20.0 | 0.24 to 0.79[1] |
| 75-26 | 31 Jan - 11 Mar 76 | Ottawa, Ontario, Canada | 26 | 18.0 | 8200 | 140.2 (mid) | N/A | 324 | N/A | -0.2 to -20.4 | 0.20 to 0.80 |
| 77-30 | 9 Jan - 8 Feb 78 | Spokane, Washington | 19 | 23.2[4] | 6760 to 7060 | 138.0 (mid) | 6260 to 11100 | 324 | 80 | 5.0 to -15.0 | 0.14 to 0.50[1] |
| 78-21 & | 22 Jan - 22 Feb 79 | St. Paul, Minnesota | 11 HISS | 6.7 HISS | 8550 | 138.0 (mid) | N/A | 324 | 90 | -10.0 to -20.0 and | 0.25 to 0.75[1] and |
| 78-21-2 | 26 Feb - 21 Mar 79 | Syracuse, New York | 15 Natural | 7.9 Natural | | | | | 90[3] | -2.5 to -12.0 | 0.06 to 0.23 |
| 79-02 | 12 Jan - 26 Mar 80 | St. Paul, Minnesota | 7 HISS 14 Natural | 4.0 HISS 9.3 Natural | 8500 | 139.0 (mid) | N/A | 324 | 90[3] | -2.0 to -12.5 | 0.10 to 0.32 |
| 80-13 | 27 Jan - 9 Mar 81 | St. Paul, Minnesota | 17 HISS 3 Natural | 15.4 HISS 3.2 Natural | 8500 | 139.0 (mid) | 15000 to 10000[2] | 324 | 90 | -4.5 to -20.5 | 0.25 to 1.0[1] |
| | | | | | | | | | 87[5] | -6.5 to 9.0 | 0.09 to 0.26 |

NOTES: [1] Programmed liquid water content
[2] Pressure altitude
[3] Indicated airspeed
[4] Total hours
[5] Calibrated airspeed

C86-TH63

# APPENDIX B-23
# UH-1H (Project No. 81-11)

## Specific Test Conditions[1]

| LWC at Aircraft (gm/m³) | OAT (°C) | Equivalent Immersion Time (min) | Wind Speed and Gustiness[1] (mph) |
|---|---|---|---|
| 0.25 | -13 | 4 | 15 M[1] |
| | -13.5 | 5 | 15 M |
| | -12.5 | 5½ | 10 M |
| | -12.5 | 6 | 10 M |
| 0.25 | -17.5 | 14 | 10 M |
| | -16 | 8¼ | 10 M |
| | -15.5 | 3½ | 10 M |
| | -15.5 | 5½ | 10 M |
| 0.25 | -18 | 10½ | 10 M |
| | -18 | 8½ | 10 M |
| | -18.5 | 6¾ | 10 M |
| 0.25 | -21.5 | 12½ | 7 L |
| | -21.5 | 5½ | 10 M |
| | -21 | 6½ | 10 M |
| | -20.5 | 6½ | 10 M |
| | -20 | 7 | 10 M |
| | -16 | 21½ | 10 M |
| | -16.5 | 10½ | 10 M |
| 0.25 | -6 | 10½ | 5 L |
| 0.25 | -14.5 | 3½ | 5 L |
| | -13.5 | 6 | 5 L |
| | -11.5 | 5¼ | 5 L |
| 0.25[2] | -12 | 5 | 10 M |
| | -11.5 | 15½ | 10 M |
| 0.25[2] | -16.5 | 4½ | 10 M |
| | -17.5 | 4½ | 7 M |
| 0.25[2] | -20 | 14 | 5 L |
| 0.40[2] | -9.5 | 4 | 11 M |
| | -9 | 13 | 11 M |
| 0.50[2] | -16 | 15 | 10 M |
| | -15 | 9 | 11 M |
| 0.50 | -6 | 7¾ | 5 L |
| 0.50[2] | -11 | 12½ | 5 L |
| 0.50 | -11 | 16 | 10 M |
| 0.50 | -15 | 7¾ | 10 M |
| 0.75 | -6 | 12 | 5 L |
| 0.75 | -10.5 | 9½ | 8 M |
| | -10.5 | 10½ | 8 M |

NOTES: [1]Gustiness: (L) = less than ± 1.5 mph.
Medium (M) = ± 1.5 to ± 3 mph
[2]ICEX Tests



086 1860

# APPENDIX B-24
## UH-1H (Project No. 82-12)
### Specific Test Conditions

| | Wind | | | | | | | Ice | | |
|---|---|---|---|---|---|---|---|---|---|---|
| NASA test | Speed (Knots | Gustiness | Water Flow lb/hr) | LWC[1] (gm/m$^3$) | Temperature (°C) | Sky Condition | Time in Cloud (min) | Thickness at BS[2] 144 (in.) | Maximum Span (%) | Documentation |
| A | 7 | Medium | 4400 | 0.4 | -12.0 | Overcast | $4\frac{1}{2}$ | 0.2 | [illegible] | Molds<br>Tracings<br>Stereo Photos |
| B | 10 | Medium | 6200 | 0.4 | -9.5 | Overcast | $4\frac{1}{4}$ | 0.3 | 65 | Molds<br>Tracings<br>Stereo Photos |
| C | 6 | Medium | 4000 | 0.4 | -17.5 | Clear | 4 | Not Measured | 85 | Molds<br>Stereo Photos |
| D | 4 | Low | 2600 | 0.4 | -21.5 | Clear | 6 | 0.2 | 92 | Molds<br>Tracings |
| E | 9 | Low | 6200 | 0.7 | -19.0 | Clear | 3 | 0.4 | 92 | Molds<br>Tracings<br>Stereo Photos |

NOTES: [1] LWC — Liquid Water Content as determined by NRC
[2] B.S. — Blade Station

C86-TH61

# APPENDIX B-25
# UH-1H (Project No. 83-23)

## Specific Test Conditions

| Flight | Weather | | | | HISS | | | | Performance | | | Ice Shapes | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Test Temperature (Deg C) | Relative Humidity (%) | Ground Temperature (Deg C) | Sky Conditions | Flow Rate (gal/min) | Liquid Water Content (gm/m³) | Particle Size -MVD- (μm) Note 1 | Time In Cloud (min:sec) | $C_T$ ($C_T$ x 10⁴) Note 2 | $N/\sqrt{\theta}$ (RPM) Note 3 | Main Rotor Power Increase at 100 KTAS (hp) Note 4 | Observed Ice Accretion (ft) | Span of Ice at Landing (ft - in.) | Thickness at Mid-Span (in.) |
| — | -13 | 55 | 0 | Clear | 11.0 | 0.53 | 35 | 5:0 | No Performance Data | | | 17 | 4 | — |
| A | -12 | 85 | -2 | Clear | 10.0 | 0.55 | 34 | 5:21 | 32.8 | 341.2 | 25 | 19 | 9 - 6 | 1/4 |
| B | -13 | 60 | -5 | Clear | 9.2 | 0.51 | 38 | 5:0 | 32.8 | 339.4 | 5 | 18 | 15 | 1/4 |
| C | -14 | 52 | -4 | Clear | 10.1 | 0.43 | 41 | 5:0 | 33.8 | 339.2 | 5 | 19 | 16 - 2 | 1/4 |
| D | -1 | 45 | -9 | Clear | 11.0 | 0.59 | 42 | 6:35 | 31.8 | 339.5 | 98 | 21 | 16 | 5/16 |
| E | -21 | 52 | -16 | Clear | 10.4 | 0.50 | 37 | 0:0 | 32.8 | 346.4 | 5 | 24 | 20 - 6 | 3/8 |
| F | -15 | 62 | -18 | Light Haze | 10.7 | 0.50 | 65 | 8:40 | 32.7 | 345.9 | 115 | 24 | 21 - 6 | 1/2 |
| G | -21 | 64 | -14 | Light Haze | 10.0 | 0.55 | 63 | 9:10 | 31.8 | 345.8 | 5 | 24 | 21 - 6 | 3/8 |
| H | -2 | 60 | -8 | Clear | 10.4 | 0.50 | 50 | 6:15 | No Performance Data | | | 24 | 21 - 2 | 8 |

NOTES: ¹MVD — Median Volumetric Diameter
²$C_T$ — Thrust Coefficient
³$N/\sqrt{\theta}$ — Referred Main Rotor Speed
⁴Main rotor power corrected to standard day conditions



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# APPENDIX B-20
# UH-60A (Project No. 81-18)
## Specific Test Conditions

| Flight Number | Icing Condition | Average L.W.C. (grams/ cubic meter) | Median Volumetric Diameters (microns) | Average Relative Humidity (percent) | Average O.A.T. (deg C) | Average True Airspeed (knots) | Average Pressure Altitudes (feet) | Total Time in Cloud (minutes) | Total Ice[2] Accreted On Visual Probe (inches) | Maximum[3] Torque Increase Per Engine Prior to Shed | Residual[3] Torque Increase After Shed | Maximum Vibration Rating Scale |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Artificial | 0.15 | 27 | 47 | -7.0 | 111 | 5660 | 60 | — | — | — | 1 |
| 2 | Artificial | 0.21 | 42 | 10 | -17.0 | 115 | 7000 | 45 | — | — | — | 4 |
| 3 | Natural | 0.42 | 20 | 100 | -7.0 | 115 | 3120 | 95 | 3.25 | 7 | 2 | 4 |
| 4 | Artificial | 0.50 | 4 | 95 | -12.0 | 97 | 8080 | 81 | — | — | — | 6 |
| 5 | Artificial | 0.49 | 82 | 35 | -6.0 | 115 | 5040 | 60 | — | — | — | 4 |
| 6 | Natural | 0.30 | 12 | 100 | -6.0 | 125 | 2960 | 59 | 2.50 | 8 | 4 | 1 |
| 7 | Natural | 0.10<br>0.20 | 9<br>9 | 100<br>100 | -15.0<br>-15.0 | 117<br>117 | 5200<br>5760 | 38<br>44 | —<br>2.50 | —<br>9 | —<br>5 | —<br>3 |
| 8 | Natural | 0.56 | 19 | 100 | -4.0 | 113 | 6680 | 43 | 3.50 | 18 | 0 | 1 |

NOTES: [1] Average Gross Weight = 16,260 pounds.
Average CG = FS 354.2.
Utility Configuration.
[2] Location of the visual probe precluded it from exposure to the spray cloud during artificial icing.
[3] Accurate measurements of torque increases and residual torque increase after a rotor ice shed were not possible during artificial icing due to constant power changes required to maintain position in the HISS cloud.
[4] Data not available.

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# APPENDIX B-27
# YEH 60A (Project No. 83-21)

## Specific Test Conditions

| Flight Number | Environment | Configuration | Average Gross Weight (lb) | Average Longitudinal CG (fs) | Average Dinsity Altitude (ft) | Average OAT (°C) | Average LWC ($gm/m^3$) | Average True Airspeed (knots) | Total Time In Cloud (min) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Artificial | ECM Retracted | 15830 | 361.4 | 6640 | -20.0 | 1.00 | 116 | 28 |
| 2 | Artificial | ECM Extended | 15640 | 360.6 | 2810 | -21.5 | 1.00 | 123 | 49 |
| 4 | Natural | ECM Extended | 15480 | 359.9 | 3630 | -11.0 | 0.35 | 127 | 75 |
| 5 | Natural | ECM Retracted | 15460 | 359.8 | 7630 | -9.0 | 0.40 | 126 | 98 |
| 6 | Artificial | ECM Extended | 15740 | 361.1 | 4700 | -5.5 | 1.16 | 120 | 46 |
| 7 | Natural | ECM Extended | 15410 | 359.4 | 2000<br>3450 | -4.0<br>-6.0 | 0.15<br>0.26 | 93<br>95 | 60<br>19 |
| 8 | Artificial | ECM Retracted, Heated DF | 16090 | 361.0 | 830 | -22.0 | 0.26 | 120 | 10 |
| 10 | Artificial | ECM Retracted, Heated DF | 16120<br>15910<br>15710 | 361.1<br>360.4<br>359.6 | 1620 | -22.5 | 0.50<br>0.75<br>1.02 | 120 | 10<br>10<br>10 |
| 12 | Natural | ECM Extended, Heated DF | 15530 | 360.1 | 5810 | -5.5 | 0.25 | 13[illegible] | 69 |
| 13 | Artificial | ECM Retracted, Heated DF | 15780 | 361.1 | 6680 | -6.5 | 1.00 | 120 | 43 |
| 14 | Natural | ECM Extended, Heated DF | 15370 | 359.4 | 7390 | -9.0 | 0.23 | 123 | 62 |

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# APPENDIX B-28
# UH-60A (Project No. 83-22)

## Specific Test Conditions[1]

| Number of Flights | Icing Environment | Configuration | Average Outside Air Temperature (°C) | Average Liquid Water Content ($gm/m^3$) | Average True Airspeed (knots) | Total Time in Cloud (hours) |
|---|---|---|---|---|---|---|
| 2 | Artificial | Fixed Provisions | -4.5 and -20 | 0.96 and 1.00 | 120 | 1.6 |
| 3 | Natural | | -8.0 to -16.0 | 0.15 to 0.30 | 123 to 134 | 3.2 |
| 1 | Artificial | ESSS, 2-tank | -15.5 | 1.03 | 120 | 0.8 |
| 1 | Natural | | -13.0 | 0.05 | 135 | 0.5 |
| 4 | Artificial | ESSS, 4-tank | -5.5 to -20 | 0.95 to 1.05 | 120 | 2.6 |
| 7 | Natural | | -3 to -21 | 0.05 to 0.36 | 107 to 125 | 14.9 |

NOTE: [1] Range of average gross weights; 12,180 to 18,530 lb
Range of center-of-gravity; FS 349.0 to FS 363.3
Range of density altitudes; 80 to 7960 feet
Average rotor speed; 258 rpm (100 percent)

C86-TH62

## APPENDIX C. INSTRUMENTATION AND SPECIAL EQUIPMENT

This Appendix presents a listing of instrumentation and special equipment that was used in addition to or instead of standard aircraft instruments to aid in evaluating performance, handling qualities, and ice accretion and shedding characteristics during icing tests conducted by and/or supported by USAAEFA. Table 1 provides an index to the test aircraft and project number where appropriate. Not all test projects have an appendix listing instrumentation and special equipment due to a lack of availability of the information.

Table 1. Index of Instrumentation and Special Equipment

| Appendix | Aircraft | USAAEFA Project No. |
|---|---|---|
| C-1 | U-21A | 77-05 |
| C-2 | CH-47C | 73-04-1 |
| C-3 | CH-47C | 78-18 |
| C-4 | YCH-47D | 79-07 |
| C-5 | YUH-60 | 76-09-1 |
| C-6 | UH-60A | 78-05 |
| C-7 | UH-60A | 79-19 |
| C-8 | UH-60A | 80-14 |
| C-9 | YUH-61 | 76-09-2 |
| C-10 | AH-1G | 73-04-2 |
| C-11 | YAH-64 | 80-08 |
| C-12 | AH-1Q | 73-04-7 |
| C-13 | BHT-412 | 80-10 |
| C-14 | UH-1H | 73-04-4 Part 1 |
| C-15 | UH-1H | 74-31 |
| C-16 | UH-1H | 74-13 |
| C-17 | UH-1H | 77-30 |
| C-18 | UH-1H | 78-21 and 78-21-2 |
| C-19 | UH-1H | 79-02 |
| C-20 | UH-1H | 80-13 |
| C-21 | JUH-1H | 81-11 |
| C-22 | UH-1H | 82-12 |
| C-23 | UH-1H | 83-23 |
| C-24 | UH-60A | 81-18 |
| C-25 | YEH-60A | 83-21 |
| C-26 | UH-60A | 83-22 |

APPENDIX C-1

INSTRUMENTATION AND SPECIAL EQUIPMENT

U-21A (Project No. 77-05)

INSTRUMENTATION

1. The test aircraft instrumentation which replaced or augmented the standard aircraft instrumentation is listed below. In addition to the special instrumentation, selected standard instrumentation such as engine torque, propeller speed, etc, was calibrated prior to the start of the evaluation. All instrumentation was installed and maintained by USAAEFA.

Airspeed (ship's system)

Altitude (ship's system)

Total air temperature (heated test system)

Ice detection system

SPECIAL EQUIPMENT

2. Both aircraft were equipped with the Rosemount series 871 ice detectors. The system was used to measure the ice severity rate, such as trace, light, etc., and not accretion. The series 871 ice detector uses an axially vibrating sensing element frequency sensitive to mass (ice) buildup. When ice builds on the sensing element, the added mass decreases the reference resonant frequency. This frequency is compared with a stable reference frequency, and when the frequency shift reaches a preset level, an icing rate signal is given. When the icing signal is given, the element is heated, deiced, and a new cycle is started. The frequency of the cycle is directly related to the rate of icing intensity or severity. The system was calibrated by Rosemount in their icing wind tunnel prior to the evaluation.

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APPENDIX C-2

INSTRUMENTATION AND SPECIAL EQUIPMENT

CH-47C (Project Number 73-04-1)

## INSTRUMENTATION

### Photopanel

1. A photopanel was used to record selected parameters on 35mm film. A film rate of one frame per second was used. The following parameters were recorded:

Airspeed (ship's system)

Altitude (ship's system)

Engine output shaft torque (both engines)

Gas producer turbine speed ($N_1$) (both engines)

Exhaust gas temperature (both engines)

Main rotor speed

Vertical speed

Total air temperature

Fuel counter and flow rates (both engines)

Time

Frame counter

Event lights

Thrust control position

Lateral cyclic control position

Longitudinal cyclic control position

Directional control position

### Magnetic Tape System

2. An Ampex Model AR700 one inch magnetic tape recorder was installed. Vertical, lateral, and longitudinal vibrations were recorded at the pilot station, the aft rotor transmission area, and the forward rotor transmission area. The Rosemount icing severity signal and the Rosemount ice accretion signal were also on magnetic tape.

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## Miscellaneous Instrumentation

3. Outside air temperature was measured using a Rosemount sensitive total temperature measuring system. Cockpit communications were recorded with a small portable cassette tape recorder, as well as with the magnetic tape data system.

## SPECIAL EQUIPMENT

### Ice Accretion Indicator Probe

4. An ice accretion indicator probe was designated, fabricated, and mounted on the test aircraft by USAAEFA personnel and was used to give the pilot a visual cue to ice buildup on the fuselage of the helicopter. The probe consists of a small symmetrical airfoil (OH-6A tail rotor section) with a 3/16-inch diameter steel rod protruding 1-1/2 inches outward from the center of the airfoil leading edge. The unit was mounted above the copilot's overhead window and was visible to the copilot during all tests. The protruding rod was masked with 1/4-inch graduations of contrasting colors which provided a method of qualitatively measuring the ice buildup on the leading edge of the airfoil.

### Ice Detection and Accretion Rate System

5. The Rosemount ice detection and accretion rate system was used to quantify icing rate and accretion while in the icing environment. The system consisted of a probe (Model 871FA) mounted on the right side of the forward pylon, a cockpit indicator (Model 512P), and an analog output which was recorded on the magnetic tape data system.

6. The sensing element of the Rosemount ice detector is a tube that vibrates axially at a resonant frequency of approximately 40 kilohertz. Axial vibration is achieved by magnetostriction and amplitudes are on the order of microinches. When ice forms on the sensing element, a change in resonant frequency occurs. The frequency change is noted by comparison with a fixed-frequency oscillator and the rate of frequency change is used to determine icing rate. Visual readout is from a meter calibrated for trace, light, moderate, and heavy icing rates. An airspeed compensation system was devised by USAAEFA personnel to adjust the icing rate system to the proper sensitivity for the true airspeed being flown. A true airspeed computation was made prior to entry into the icing environment based on temperature, altitude, and indicated airspeed. This airspeed was related to an external resistance which compensated the icing rate system sensitivity to the selected true airspeed. The Rosemount icing rate system installed on the test aircraft was wind tunnel-calibrated by the manufacturer. Table 1 contains the information supplied to USAAEFA to cross-reference display indications with LWC.

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Table 1. Rosemount Icing Rate System Wind Tunnel Liquid Water Content Calibration [1]

| Meter Indication | Measured Liquid Water Content (gram/meter$^3$) |
|---|---|
| T (trace) | 0.09 |
| L (light) | 0.16 |
| M (Moderate) | 0.29 |
| H (heavy) | 0.60 |

[1] Calibration for icing rate system, Model 512P, SN 4

E

APPENDIX C-3

INSTRUMENTATION AND SPECIAL EQUIPMENT

CH-47C (Project Number 78-18)

## INSTRUMENTATION

1. In addition to, or instead of standard aircraft instruments, calibrated test instrumentation was installed aboard the test aircraft. This instrumentation was installed and maintained by the contractor. Data were recorded by hand from cockpit instruments and on magnetic tape.

2. The calibrated test instrumentation used during this program are contained in the following:

Pilot Station

Airspeed (prod)

Altitude (prod)

Free air temperature (prod)

Rate of climb (prod)

Rotor rpm (test)

Engine torque (both engines) (prod)

Engine turbine inlet temperature (both engines) (prod)

Engine $N_1$ (both engines) (prod)

Collective control position

Event switch

Instrumentation controls

Time of day

Run number

Icing rate

Deice system operation indicator lights

Deicing Engineer Station

Ice detector select switch

Deice system operation indicator lights

Run number

<u>Tape Recorded Parameters</u>

Airspeed

Altitude

Free air temperature

Rotor speed (test)

Rate of climb

Engine torque (both engines)

Engine $N_1$ (both engines)

Collective control position

Time

Run number

Pitch attitude

Vibration

- Station 95 vertical accelerometer
- Lateral accelerometer
- Longitudinal accelerometer
- Station 360 vertical accelerometer
- Lateral accelerometer
- Longitudinal accelerometer

Rotor deice voltage phase A

Rotor deice voltage phase B

Rotor deice voltage phase C

Rotor deice current phase A

Rotor deice current phase B

Rotor deice current phase C

Forward fixed link load

Icing rate (front left probe)

Probe deice cycle on time (all probes)

SPECIAL EQUIPMENT

Ice Detector System

3. Three Rosemount 871FA121 ice detectors were installed on the test aircraft. The detector on the left side of the forward pylon was utilized as the icing rate indicator in the cockpit, providing a continuous readout of icing rate in terms of T, L, M and H. It was also recorded by the data system as a record of actual icing rate and accumulation. This detector's (SN 021) calibration indicated that it deiced (cycled) after an accumulation of 0.037 inches of ice. The other forward pylon detector and the aft pylon detector were utilized by the rotor blade deice system. The forward detector deiced after an accumulation of 0.039 inches and the aft detector after an accumulation of 0.020 inches of ice. Either of these detectors could be selected by the engineer to activate the blade deice system. A light in the cockpit indicated each deice cycle of the detector selected to run the system. The deice cycle from both forward and aft detectors were recorded. Either location, forward or aft, was acceptable to initiate operation of the deice system. While operating in a natural icing environment, the frequency of operation of the detectors was compatible with their respective calibrations.

E

## APPENDIX C-4

## INSTRUMENTATION AND SPECIAL EQUIPMENT

## YCH-47D (Project No. 79-07)

### INSTRUMENTATION

1. In addition to, or instead of standard aircraft instruments, calibrated test instrumentation was installed aboard the test aircraft. The instrumentation was installed and maintained by Boeing Vertol. Data were recorded by hand from cockpit instruments, and on PCM encoded magnetic tape.

2. The test instrumentation available during this program is listed below:

Pilot Station

- Run number
- Time of day
- Event switch
- Liquid water content meter (Leigh)
- Rosemount deice indicator
- Deice system operation indicator lights and controls

Magnetic Tape

- Airspeed
- Altitude (pressure)
- Rate of climb
- Rotor rpm
- Engine torque (both engines)
- Engine $N_1$ (both engines)
- Fuel flow (both engines)
- Fuel temperature (both engines)
- Longitudinal stick position
- Lateral stick position
- Directional control position
- Collective stick position
- Pitch attitude
- Roll attitude
- Yaw attitude
- Pitch rate
- Roll rate
- Yaw rate
- Time code
- Event pulse
- Cruise guide voltage
- Vibration
    - Station 50 (2 vertical pilot and copilot seats)
    - Station 95 (3 axis)
    - Station 360 (3 axis)
    - Station 585 (3 axis)
- Outside air temperature

Liquid water content (Leigh)
Rotor deice voltage (3)
Rotor deice current (3)
Rosemount icing rate (fore and aft detectors)
Rotor blip

## SPECIAL EQUIPMENT

### Rosemount Ice Detector

3. Two Rosemount Model 871A nonaspirated ice detectors were mounted on the aircraft; one each on the left side of the fore and aft pylons. Each detector measured accreted ice to a depth of 0.02 inches on the probe. At that point, the probe deiced and a new cycle began. With the blade deice system in the automatic mode, either of the Rosemount detectors could be chosen to activate the system after three probe deice cycles. Cockpit indication consisted of lights showing when the probe was being deiced.

### Leigh Detector

4. A single Leigh Ice Detector Unit, Mark XII (IDU-3) was mounted on the right side of the forward pylon. As with the Rosemount probe, ice accreted to a present level, then the probe deiced. The deice cycles are timed and the rate of accretion is calibrated in terms of LWC. The cockpit indication is a gage showing ice severity. The gage is divided into four zones:

| Zone | Severity | Color | LWC |
|---|---|---|---|
| 1 | Trace | White | 0-0.05 $gm/m^3$ |
| 2 | Light | Green | 0.05-0.5 $gm/m^3$ |
| 3 | Moderate | Yellow | 0.5-1.0 $gm/m^3$ |
| 4 | Heavy | Red | 1.0-2.0 $gm/m^3$ |

### Visual Ice Indicators

5. A visual ice accretion indicator was mounted on the test aircraft to give the pilot a visual cue of ice buildup on the helicopter. It was composed of a small symmetrical air foil (OH-6A tail rotor blade section) with a 3/16 inch diameter steel rod protruding 1-1/2 inches out from the leading edge at the center. The protruding rod was painted with multi-colored 0.2 inch strips to provide a reference for ice thickness estimation. The unit was mounted on the pilot's door facing forward.

6. Outside the left window was a "V" shaped linear ice accretion meter known as the "Harvey Smith" indicator. The copilot sighted the device in such a way that the apex of the "V" was at zero on the calibrated scale. The ice depth was read on the scale at the point where the accreted ice on one leg of the "V" crossed the vernier scale on the other leg. A calibration chart was used to determine LWC from the indicated icing rate (mm/min) and airspeed.

Photographic Equipment

7. A still camera was mounted just aft and to the right of the forward pylon. Activated from the instrumented rotor blip through an intervelometer, the camera took pictures of one of the aft rotor blades during flight.

8. Two fiber optic television cameras were installed on the number 2 engine inlet. One lens was focused on the underside of the inlet screen at the 11 o'clock position. The other focused on the engine "D" ring at the 12 o'clock position. A video monitor and tape recorder were mounted in the cabin area.

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APPENDIX C-5

INSTRUMENTATION AND SPECIAL EQUIPMENT

YUH-60 (Project No. 76-09-1)

INSTRUMENTATION

1. In addition to, or instead of, standard aircraft instruments, sensitive calibrated instrumentation was installed aboard the test aircraft and maintained by the contractor. Data were recorded from the cockpit instrumentation and the specially installed instrumentation system. Data were recorded on flight data cards and magnetic tape (PCM and FM). Selected parameters were observed real time via air-to-ground telemetry (TM).

2. The sensitive instrumentation, calibrated ship's system instrumentation, and related special equipment installed are listed below.

Pilot/Copilot Panel

Airspeed (ship's system)
Altitude (ship's system)
Rate of climb/descent (ship's system)
Free air temperature (ship's system)
Rotor speed (digital)
Engine torque (both engines)
Engine turbine inlet temperature (both engines)
Engine gas generator speed (both engines)
Engine power turbine speed (both engines)
Engine inlet particle separator differential pressure (both engines)
Stabilator position
Control position:
- Longitudinal
- Lateral
- Directional
- Collective

Star load

Pilot/Copilot Station

Event switch
Visual ice accretion probe
Deice controls and lights
Vibration meter (Chadwick-Helimuth)

USAAEFA Engineer Station

Instrumentation controls and lights
Main and tail rotor camera switches
Event switch
Time of day
Run number
Fuel remaining
Free air Temperature

Deicing Engineer Station

Icing rate (Rosemount 871FA)
Icing condition (Normalair-Garrett)
Main rotor blade surface temperatures (8)
Tail rotor blade surface temperatures (2)
Main rotor deice system potentiometers (4)
Tail rotor deice system potentiometers (4)
Rosemount ice detector test switch

Digital (PCM) Data Parameters

Airspeed (ship's system)
Altitude (ship's system)
Rate of climb (ship's system)
Free air temperature
Rotor speed
Engine gas generator speed (both engines)
Engine power turbine speed (both engines)
Engine output shaft torque (both engines)
Engine turbine gas temperature (both engines)
Fuel flow (both engines)
Fuel used (both engines)
Engine inlet particle separator duct differential pressure (both engines)
Control position:
    Longitudinal
    Lateral
        Directional
        Collective
        Engine condition level (both engines)
Aircraft pitch attitude
Tail rotor shaft torque
Stabilator position
Main rotor camera correlation pulse
Tail rotor camera correlation pulse
Main rotor blade surface temperatures (8)
Tail rotor blade surface temperatures (2)
Engine anti-ice valve position (No. 1)
Engine inlet duct anti-ice valve position (No. 1)
Generator (No. 1):
        Frequency
        Voltage (A phase)
        Current (A, B, and C phases)
Deice/anti-ice system electrical parameters:
        Main rotor voltage (A, B, and C phases)
        Main rotor current (A, B, and C phases)
        Tail rotor voltage (A, B, and C phases)
        Tail rotor current (A, B, and C phases)
        Windshield voltage (A, B, and C phases)
Rosemount icing rate
        Normalair-Garrett icing condition
        Time of day

Run number
Pilot and engineer event pulse

Analog (FM) Data Parameters

Vibration (accelerometer location):
- Pilot station vertical
- Pilot station lateral
- Pilot station longitudinal
- Aircraft cg vertical
- Aircraft cg lateral
- Aircraft cg longitudinal
- Main transmission (top) vertical
- Main transmission (top) lateral
- Main transmission (top) longitudinal
- Tail rotor gearbox vertical
- Tail rotor gearbox lateral
- Tail rotor gearbox longitudinal

3. In addition to standard aircraft instruments, sensitive calibrated instrumentation was installed aboard the CH-47C spray aircraft. This instrumentation was used to establish the desired test conditions during the icing flights and is listed below.

Airspeed
Altitude
Free air temperature
Dew point
Water flow rate
Bleed air pressure
Radar distance (separation between test and spray aircraft)

## SPECIAL EQUIPMENT

### Camera System

4. Two Teledyne 16mm camera systems, Model DBM 44, were installed on the test aircraft to photograph the main and tail rotor blades inflight. The camera film magazine held 200 feet of film and camera shutter speeds of up to 400 frames per second (fps) were available. Another 16mm high-speed hand-held motion picture camera was located on board the chase aircraft and was used to document the test aircraft both in the spray cloud and after exit from the cloud. Additionally, 35mm color slide and black and white still cameras were used for documentation both in the air and on the ground following each icing flight.

5. The main rotor camera was mounted on top of the main rotor hub assembly. It was positioned over one of the four main blades so that the top of the blade was visible out to approximately 80 percent of its span. The camera was encased in a specially built box with an electrically heated window in front of the camera lens. A shutter speed of 250 fps was used.

6. The tail rotor camera was mounted on the right side of the tail cone facing aft toward the tail rotor. The camera installation was covered with an electrically heated fairing to prevent ice buildup. A shutter speed of 400 fps was used.

Ice Detectors

7. Two ice detectors (a Rosemount Model 871FA and a Normalair-Garrett) were installed on the test aircraft to correlate the icing severity levels experienced by the test aircraft with the LWC established by the CH-47C spray aircraft. A third ice detector (Rosemount Model 871FA) was installed as part of the aircraft deice system. Additionally, a visual ice accretion probe was installed on the test aircraft to document ice accumulation.

8. The Rosemount Model 871FA ice detector is an electromechanical device which transmits an electronic signal when a specified thickness of ice is present on the sensing probe. Two Model 871FA detectors were mounted on the test aircraft. The contractor ice detector was aspirated and used to trigger the aircraft deice system ON and OFF in the AUTO mode. This deice system detector was mounted on a pad located between the left engine compartment cooling scoops. The instrumentation detector was mounted on a pad located between the right engine compartment cooling scoops. The instrumentation detector incorporated a Rosemount Model 512P icing rate meter and test switch installed in the aft cargo compartment on the deice engineer panel.

9. The operation of the two detectors is identical. The sensing element of the ice detector is an axially vibrating tube whose natural frequency changes with ice accumulation. Tube vibration is achieved with a magnetostrictive oscillator (MSO). The reference oscillator signal is summed with the signal from the MSO to produce a difference frequency (the output of the mixer). The frequency-to-voltage converter changes the frequency difference voltage, and when this voltage reaches a preset value corresponding to the accumulation of 0.020 inch (0.5mm) of ice, an output signal is provided to the timer. The timer initiates the probe heating cycle, which purges the probe of the accumulated ice. Also, a constant voltage output signal is provided. The signal from the instrumentation detector was recorded on the data package magnetic tape. After the probe heating cycle is completed, the probe is ready to accrete ice and the sequence is repeated.

10. The frequency-to-voltage converter of the MSO also provides a variable voltage analog output corresponding to ice thickness. The instrumentation detector signal was differentiated and was displayed on the Rosemount Model 512P icing rate meter on the deice engineer panel.

11. The press-to-test button on the deice engineer panel was provided to check system operation. Depressing and holding the button creates a difference frequency which simulated ice accumulation on the probe. Proper system operation was indicated by illumination of a red light and deflection of the icing severity needle.

12. The Normalair-Garrett ice detector is an inferential type detector. Unlike the Rosemount detector which allows ice to accrete on a probe, the Garret detector senses the amount of free water in the atmosphere. Specifically, the system measures the impingement and rate of supercooled liquid water and icing surface temperature. The system consists of three major components: moisture-sensing head, control module, and icing severity indicator.

13. The Normalair-Garrett moisture-sensing head was mounted on the test aircraft fuselage just aft of the right gunner window and below the maintenance

step. The water and skin temperature-sensing head consists of two cylindrical heater/sensor probes mounted on a short airfoil section mast. The front heater is exposed directly to the airflow and impinging water droplets. The rear heater is housed within the inertia separator, which prevents any water droplets impinging on its surface. Both heaters are maintained at a constant electrical temperature by the electronic control module. The physical proportions of the two probes and the recovery factor of the inertia separator give equal cooling to the two probes and the recovery factor of the inertial separator give equal cooling to the two probes under dry air conditions; therefore, the same electrical power is required to make the temperature of the two probes equal. When supercooled water droplets are present, an increase in power is required by the front probe to maintain equality of temperature with the rear probe. The difference in power levels between the front and rear probes is, therefore, a function of the water evaporated from the front probe in unit time. This power difference is processed by the electronic control module and presented on the cockpit indicator in terms of icing severity ($gm/m^3$).

14. The icing surface temperature is obtained indirectly by a temperature sensor, which is part of the servo control system, maintaining the sensing head support mast at a temperature set above 0°C. This temperature signal is used to inhibit the indicator at that skin temperature at which no ice can form.

15. In order to check the complete system for correct functioning, a self-test facility is provided on the cockpit panel. When the self-test switch is activated, an electrical imbalance of the front probe temperature is created, which simulates cooling of the probe by water droplets. At the same time, the temperature sensor cut-out is disconnected to allow the check to be carried out above freezing conditions. The resulting icing severity indicator deflection and warning lamp illumination indicate that both the sensing head and control circuits are operational.

Visual Ice Accretion Probe

16. A visual ice accretion indicator probe was fabricated and installed on the test aircraft. It was used to give additional visual cues of ice buildup on the aircraft fuselage. The probe was composed of a small symmetrical airfoil section (OH-6A tail rotor blade sections) with 3/16 inch diameter steel rod protruding outward from the leading edge at the center span. The protruding rod was painted with 1/4 inch stripes of contrasting colors which provided a comparison basis for visual ice measurements. The probe was mounted on the left cockpit door just below the window.

Telemetry and Data Reduction System

17. A portable TM monitoring and data reduction system was fabricated to allow on-site data analysis. It consisted of the following:

Nems-Clarke Type R10376 solid state TM receiver
EMR-Schlumberger Model 720 PCM bit synchronizer
EMR-Schlumberger Model 2731 PCM frame synchronizer
EMR-Schlumberger Model 713 programmable word selector
Hewlett-Packard Model 5245L electronic counter
Hewlett-Packard Model 4204A oscillator

18. The TM receiver had a line-of-sight range or approximately 20 to 30 nautical miles and monitored signals on a 1435- to 1540-MHz band. The system converted these signals into a real time display of 12 PCM data channels on the brush recorders and 6 FM data channels on the oscillograph. The channels monitored during a flight were chosen by the project engineer from among any of the channels being recorded by the airborne magnetic tape system. The channels displayed could be changed at any time during the flight.

19. The package allowed for postflight strip-out of the flight tape. Each time the flight tape was run through the system, 12 PCM and 6 FM channels could be processed. The electronic counter allowed actual PCM data counts to be compared with pen movements. The flight tape could rerun until all desired data channels were stripped out. The system allowed for a tape search for specified time slice and digital display of the data.

## APPENDIX C-6

## INSTRUMENTATION AND SPECIAL EQUIPMENT

## UH-60A (Project No. 78-05)

### Instrumentation

1. In addition to standard aircraft instruments, calibrated instrumentation was installed aboard that test aircraft and maintained by the contractor. Data from the cockpit instrumentation was recorded on flight data cards, and from the specially installed instrumentation system on magnetic tape (PCM and FM).

2. The ship's system instrumentation and test instrumentation are listed below:

Pilot/Copilot Panel

Airspeed (ship's system)
Altitude (ship's system)
Altitude (radar)
Rate of climb/descent (ship's system)
Free air temperature (ship's system)
Rotor speed
Engine torque (both engines)
Engine turbine gas temperature (both engines)
Engine gas generator speed (both engines)
Engine power turbine speed (both engines)
Stabilator position
Control position:
- Longitudinal
- Lateral
- Directional
- Collective

Digital (PCM) Data Parameters

Airspeed
Altitude (pressure)
Altitude (radar)
Free air temperature
Engine torque (2)
Fuel flow rate (2)
Fuel totalizer (2)
Measured gas temperature (2)
Power turbine speed (2)
Gas turbine speed (2)
Engine bleed air pressure (2)
Engine bleed air temperature (2)
Main rotor speed
Main rotor torque
Tail cone stresses (4)
Tail pylon stresses (4)
Stabilator stresses (4)

Stabilator actuator load
Main transmission walking beam load
Main rotor bridge support stress
Main and tail rotor 1/rev & 4/rev
Vibration (accelerometer location):
    Main rotor transmission (3)
    Tail rotor gearbox (3)
    CG
    Pilot seat (3)
    Copilot seat vertical and longitudinal
    Stabilator tip left, vertical and longitudinal
    Stabilator tip right, vertical and longitudinal
    No. 1 and 2 engine exhaust frame, vertical and horizontal

3. In addition to standard aircraft instruments, calibrated instrumentation was installed aboard the CH-47C spray aircraft. This instrumentation was used to establish the desired test conditions during the icing flights and is listed below.

Airspeed
Altitude
Free air temperature
Dew point
Water flow rate
Bleed air pressure
Radar distance (separation between test and spray aircraft)

## APPENDIX C-7

## INSTRUMENTATION AND SPECIAL EQUIPMENT

## UH-60A (Project No. 70-19)

1. The test instrumentation was installed, calibrated, and maintained by USAAEFA personnel. Data were measured with calibrated instrumentation and displayed or recorded as indicated below.

<u>Pilot's Panel</u>

Liquid water content (Rosemount Probe)

<u>Copilot Panel</u>

Airspeed (ship's system)
Pressure altitude (ship's system)

<u>Engineer Panel</u>

Instrumentation controls
Free air temperature
Time code display
Run number
Fuel flow rate
Fuel used
Control position:
- Longitudinal
- Lateral
- Directional
- Collective

Stabilator position

<u>Digital (PCM) Data Parameters</u>

Airspeed (ship's system)
Altitude (ship's system)
Total air temperature
Rotor speed
Gas generator speed**
Fuel used**
Engine fuel flow**
Engine output shaft torque**
Engine measured gas temperature**
Control position:
- Longitudinal
- Lateral cyclic
- Directional
- Collective

Stability augmentation position:
- Longitudinal
- Lateral

Directional
Stabilator angle of incidence
Aircraft attitude:
Pitch
Roll
Yaw
Aircraft angular velocity:
Pitch
Roll
Yaw
Engine inlet surface temperature**
Customer bleed air pressure**
Engine anti-ice valve position**
Engine inlet duct anti-ice valve position**
Generator (No. 1, No. 2, and APU):
Voltage (A phase)
Current (A phase)
Deice/anti-ice system electrical parameters:
Main rotor voltage (A phase)
Main rotor current (A phase)
Tail rotor voltage (A phase)
Tail rotor current (A phase)
Windshield voltage (A phase)
Windshield current (A phase)
Rosemount icing rate
Time of day
Run number
Pilot and engineer event pulse
**Both Engines

Analog (FM) Data Parameters

Vibration (accelerometers)
Pilot station vertical
Pilot station lateral
Pilot station longitudinal
Copilot station lateral
Aircraft cg vertical
Aircraft cg lateral
Aircraft cg longitudinal
Main transmission (top) vertical
Main transmission (top) lateral
Main transmission (top) longitudinal
Tail rotor gearbox vertical
Tail rotor gearbox lateral
Tail rotor gearbox longitudinal
Right transmission support beam vertical
Right transmission support beam lateral
Right transmission support beam longitudinal
Left transmission support beam vertical
Left transmission support beam lateral
Left transmission support beam longitudinal
Right stabilator tip vertical

Right stabilator tip longitudinal
Left stabilator tip vertical
Left stabilator tip longitudinal
Vibration (velocity):
Exhaust frame vertical (both engines)
Exhaust frame longitudinal (both engines)
Main rotor longitudinal star load

Airspeed Calibration

2. The airspeed system position error contained in the Safety-of-Flight Release was used to determine calibrated airspeed.

## SPECIAL EQUIPMENT

### Camera Systems

3. One Canon 16mm camera system was installed on the test aircraft (right side of the tailcone) to photograph the tail rotor and horizontal stabilator inflight. The camera film magazine held 100 ft of film and camera shutter speeds of up to 64 frames per second (fps) were available. Another 16mm high-speed hand-held motion picture camera was located on board the chase aircraft and was used to document the test aircraft both in the spray cloud and after exit from icing encounters. Additionally, 35mm color slide and black and white still cameras were used for documentation both in the air and on the ground following icing flight.

4. The tail camera was mounted on the right side of the tail cone facing aft toward the tail rotor. The camera installation was covered with a fairing to prevent ice buildup. A shutter speed of 64 fps was used.

### Visual Ice Accretion Probe

5. A visual ice accretion indicator probe was fabricated and installed on the test aircraft. It was used to give additional visual cues of ice buildup on the aircraft fuselage. The probe was composed of a small symmetrical airfoil section (OH-6A tail rotor blade sections) with 3/16 inch diameter steel rod protruding outward from the leading edge at the center span. The protruding rod was painted with 1/4 inch stripes of contrasting colors which provided a comparison basis for visual ice measurements. The probe was mounted on the left cockpit door just below the window.

## APPENDIX C-8

## INSTRUMENTATION AND SPECIAL EQUIPMENT

## UH-60 (Project No. 80-14)

1. The test instrumentation was installed, calibrated, and maintained by USAAEFA personnel. Data were measured with calibrated instrumentation and displayed or recorded as indicated below.

Pilot/Copilot Panel

Airspeed (ship's system)
Altitude (ship's system)
Altitude (radar)
Rate of climb/descent (ship's system)
Free air temperature (ship's system)
Free air temperature (sensitive)
Rotor speed (sensitive)
Engine torque (both engines)
Engine turbine gas temperature (both engines)
Engine gas generator speed (both engines)
Engine power turbine speed (both engines)
Control position:
- Longitudinal
- Lateral
- Directional
- Collective

Icing rate (ship's system)

Engineer Panel

Instrumentation controls
Free air temperature
Time code display
Run number
Fuel flow
Fuel used (totalizer)
Control position:
- Longitudinal
- Lateral
- Directional
- Collective

Stabilator position

Digital (PCM) Data Parameters

Airspeed (ship's system)
Altitude (ship's system)
Observed air temperature
Main rotor speed
Engine gas generator speed**
Fuel used**

Engine fuel flow**
Engine output shaft torque**
Engine measured gas temperature**
Control position:
    Longitudinal cyclic
    Lateral cyclic
    Directional
    Collective
Stability augmentation position:
    Longitudinal
    Lateral
    Directional
Aircraft attitude
    Pitch
    Roll
    Yaw
Aircraft angular velocity
    Pitch
    Roll
    Yaw
Engine inlet surface temperature**
Customer bleed air pressure**
Engine anti-ice valve position**
Engine inlet duct anti-ice valve position**
Engine inlet modulating valve temperature**
Generator (No. 1, No. 2, and APU)
    Voltage (A phase)
    Current (A phase)
Deice/anti-ice system electrical parameters
    Main rotor voltage (A phase)
    Main rotor current (A phase)
Rosemount icing rate (DC voltage to cockpit meter)
Time of day
Run number
Pilot and engine event pulse

Analog (FM) Data Parameters

Vibration (accelerometers)
    Pilot station vertical
    Pilot station lateral
    Pilot station longitudinal
    Copilot station vertical
    Copilot station longitudinal
    Aircraft cg vertical
    Aircraft cg lateral
    Aircraft cg longitudinal

Airspeed Calibration

2. The airspeed system position error contained in the Airworthiness Release was used to determine calibrated airspeed.

## SPECIAL EQUIPMENT

### Camera System

3. High-speed hand-held 16mm motion picture cameras were located on board the chase aircraft and spray aircraft and were used to document the test aircraft both in the spray cloud and after exit from icing encounters. Additionally, 35mm color slide and black and white still cameras were used for documentation both in the air and on the ground following each icing flight.

### Visual Ice Accretion Probe

4. A visual ice accretion indicator probe was fabricated and installed on the test aircraft fuselage. It was used to give additional visual cues of ice buildup on the aircraft fuselage. The probe consisted of a small symmetrical airfoil section (OH-6A tail rotor blade sections) with a 3/16 inch diameter steel rod protruding outward from the leading edge at the center span. The protruding rod was painted with 1/4 inch stripes of contrasting colors which provided a comparison basis for visual ice measurements. The probe was mounted on the left cockpit door just below the window.

### Cloud Sampling Equipment

5. An instrumentation package was installed during selected flights to sample the natural and artificial icing cloud environments. The equipment was provided, maintained and the data analyzed by Meteorological Research Incorporated (MRI). An axial scattering probe (ASP) was installed on the right side of the aircraft and a cloud particle spectrometer was installed on the left side. A detailed description of this equipment is contained in MRI technical report, "Droplet Size and Liquid Water Characteristics of the USAAEFA (CH-47) Helicopter Spray System and Natural Clouds as Sampled by a JUH-1H Helicopter," MRI 80 FR-1748 dated August 1980.

APPENDIX C-9

INSTRUMENTATION AND SPECIAL EQUIPMENT

YUH-61A (Project No. 76-09-2)

## INSTRUMENTATION

1. In addition to, or instead of, standard aircraft instruments, sensitive calibrated instrumentation was installed aboard the test aircraft and maintained by the contractor. Data were recorded from the cockpit instrumentation and specially installed instrumentation system. Data were recorded on flight data cards and magnetic tape (PCM and FM). Selected parameters were observed real time via air-to-ground telemetry. Flight crew comments were recorded on a portable tape recorder.

2. The sensitive instrumentation, calibrated ship's system instrumentation, and related special equipment installed are listed below.

### Pilot Station

Data recorder switch
Event switch

### Pilot Panel

Airspeed
Altitude (ship's system)
Altitude (radar)
Rotor speed (digital)
Rotor speed (ship's system)
Engine torque (both engines)
Engine turbine gas temperature (both engines)
Engine gas generator speed (both engines)
Control position:
- Longitudinal
- Lateral
- Directional
- Collective
- Tail rotor slider

Horizontal tail position
Center-of-gravity normal acceleration

### Copilot/Engineer Station

Instrumentation controls and lights
On-board camera controls and lights
Data recorder switch
Event switch
Visual ice accretion probe

Copilot/Engineer Panel

Airspeed
Altitude
Rotor speed
Engine torque (both engines)
Free air temperature
Main rotor blade temperature
Fuel used (both engines)
Deice system ice detector signal light
Rosemount icing rate
Normalair-Garrett icing condition
Integral particle separator duct differential pressure (both engines)
Time code display
Run number

Digital (PCM) Data Parameters

Airspeed
Altitude (ship's system)
Altitude (radar)
Rate of climb
Free air temperature
Rotor speed
Engine gas generator speed (both engines)
Engine power turbine speed (both engines)
Engine output shaft torque (both engines)
Engine turbine gas temperature (both engines)
Fuel flow (both engines)
Fuel used (both engines)
Integral particle separator duct differential pressure (both engines)
Control position:
- Longitudinal
- Lateral
- Directional
- Collective
- Engine condition lever (both engines)

Tail rotor slider
Yaw compensator actuator position
Horizontal tail position
Main rotor shaft bending
Main rotor and tail rotor cameras:
- Correlation pulse
- Run command
- Failure signal
- Out of phase signal
- Film used

Engine transmission nose fairing temperature (both engines)
Engine transmission fairing fold temperature (both engines)
Main rotor blade blanket temperature
Generator No. 1:
- Frequency
- Voltage (A, B, and C phase)

Current (A, B, and C phase)
Deice/anti-ice systems electrical parameters:
Main rotor voltage (A phase)
Main rotor current (A phase)
Tail rotor voltage (A-B and B-C phase)
Tail rotor current (A and C phase)
Horizontal stabilizer voltage (left and right side)
Horizontal stabilizer current (left and right side)
Engine transmission fairing voltage (No. 1 engine)
Engine transmission fairing current (No. 1 engine)
Windshield voltage (single-phase)
Windshield current (single-phase)
Rosemount icing rate (instrumentation system)
Rosemount icing rate (ship's system)
Normalair-Garrett icing condition
Pitch attitude
Roll attitude
Time code
Run number
Event marker

Analog (FM) Data Parameters

Main rotor blade camera correlation
Event marker
Voice
Vibration (accelerometers):
Pilot seat (vertical, lateral, and longitudinal)
Copilot seat (vertical, lateral, and longitudinal)
Instrument panel (right side vertical and lateral)
Instrument panel (left side vertical)
Center of gravity (vertical, lateral, and longitudinal)
Main rotor transmission (vertical, lateral, and longitudinal)
Tail rotor transmission (vertical, lateral, and longitudinal)

3. In addition to standard aircraft instruments, sensitive calibrated instrumentation was installed aboard the CH-47C spray aircraft. This instrumentation was used to establish the desired test conditions during the icing flights and is listed below.

Airspeed
Altitude
Free air temperature
Dew point
Water flow rate
Bleed air pressure
Radar distance (separation between test and spray aircraft)

SPECIAL EQUIPMENT

Camera Systems

4. Two 16mm high-speed, hand-held motion picture cameras were used to document ice accretion characteristics of the test aircraft. One camera was located on

board the CH-47C spray aircraft and was used while the test aircraft was in the spray cloud. The other camera was located on board the chase aircraft and was used to document the test aircraft both in the spray cloud and after exit from the cloud. Additionally, 35mm slide and black and white still cameras were used for documentation both in the air and on the ground following each icing flight.

5. In addition to the chase and HISS high-speed photography, documentation of main and tail rotor condition was achieved using nonrotating 16mm high-speed cameras mounted on board the test aircraft. The main rotor blade camera was located in the cargo compartment and viewed the lower surface of the main rotor blades through the right-hand forward cargo door window. A second camera, mounted on the left side of the tail boom at the fold hinge, was used to photograph the leading edge of the tail rotor blades and a section of the left-hand horizontal stabilizer. A camera control panel was mounted just aft of the cockpit center console with master power switch and a run switch (ON - OFF) for each camera. With the master power switch , power was supplied to the camera motors, electronics, and heaters.

6. The cameras manufactured by Photo-Sonic Inc., were 16mm Model 1PL cameras with phase lock kits and 1200-foot film magazines. Shutter speeds of 16 to 500 frames per second could be selected. The cameras were synchronized to photograph the blades at fixed aircraft azimuths. Synchronization was achieved by triggering the camera shutter through the phase lock kit with a multiplexed and phase compensated 1/rev signal. The main rotor camera had the capability of photographing blades at four or eight frames per rotor revolution. Shutter speeds up to 1/1800 second were used at four frames per revolution. The tail rotor camera had the capability for synchronization at one or two frames per tail rotor revolution. Design characteristics are listed below.

| | |
|---|---|
| Temperature | -65 to +160°F |
| Vibration | 5 to 17 Hz at 0.7-inch double amplitude |
| | 17 to 4000 Hz at 10g |
| Acceleration | 25g (three major axes) |

7. The main rotor blade camera was mounted on a square cross-section beam attached to the vertical aircraft support structure at FS 129 and 201 on the right side of the cabin interior. The span of the beam was the span of the cargo door opening. A Winter Engineering Company Model 1610B mount with two degrees of adjustment (pitch and yaw) and quick-disconnect features was attached to the beam for camera mounting. A 5.3mm lens was used on the main rotor camera, which provided a field-of-view from inboard of the pendulum vibration absorbers to the blade tips.

8. The tail rotor camera was mounted in a water-ti box attached to the left-hand of the tail boom at the tail fold hinges. A secondary support attachment was made at the first vertical aircraft support forward of the fold hinge. The camera was mounted inside the box on a Winter Engineering Company mount. A heated window provided by burg Plate Glass was used to ensure a clear viewing surface.

Icing Detectors

9. Two icing detectors were installed on the test aircraft to correlate the icing severity levels experienced by the test aircraft with the LWC established by the CH-47C spray aircraft. A third ice detector was installed as an integral component of the aircraft deice system. A visual ice accretion probe was also installed on the test aircraft to observe icing rates. These items are described in the following paragraphs.

10. The Rosemount Model 871FA ice detector is an electromechanical device which transmits an electronic signal when a specified thickness of ice is presented on the sensing probe. Two Model 871FA detectors were mounted on the test aircraft. The Boeing Vertol deice system detector was mounted on the aircraft nose in front of the copilot windshield (FS 24.5, left BL 18, WL 150). The instrumentation Rosemount detector was mounted in front of the right gunner window (FS 85, right BL 46, WL 150). The instrumentation Rosemount detector was connected to a cockpit control panel.

11. The operation of the two detectors is identical. The sensing element of the ice detector is an axially vibrating probe whose natural frequency changes with ice accumulation. Probe vibration is achieved with the magnetostrictive oscillator (MSO). The reference oscillator signal is summed with the signal from the MSO to produce a difference frequency (the output of the mixer). The frequency-to-voltage converter changes the difference frequency to a voltage, and when this voltage reaches a preset value corresponding to the accumulation of 0.020 inch (0.5mm) of ice, an output signal is provided to the timer The timer initiates the probe heating cycle which purge the probe of the accumulated ice. A constant-voltage output signal is pro ded which the Boeing Vertol deice system uses to trigger the control unit. The signal from the Rosemount detector illuminates a red light on the cockpit control panel and is recorded on magnetic tape. After the probe heating cycle is completed, the probe is ready to accrete ice and the sequence is repeated.

12. The frequency-to-voltage converter of the MSO also provides a variable-voltage analog output corresponding to ice thickness. The Rosemount detector signal was differentiated and displayed in the cockpit as an icing severity on the Rosemount Model 512P icing rate meter. The Boeing Vertol detector ar og output was recorded on magnetic tape for data analysis purposes.

13. The press-to-start button the cockpit panel was provided to check system operation. Depressing and holding the button creates a difference frequency which simulates ice accumulation on the probe. Proper system operat  is indicated by illumination of the red light and deflection of the icing severity needle.

14. The Normalair-Garrett ice detector is an inferential-type detector. Unlike the Rosemount detector, which allows ice to accrete on a probe. the Garrett senses the amount of free water in the atmosphere. Specifically, the system measures the impingement rate supercoole liquid water and icing surface temperature. The system corsists of three major components: moisture sensing head, control module, and icing severity indicator. 15. The Normalair-Garrett moist e sensing head was mounted on the test aircraft above the Rosemount detector probe. The water and skin temperature sensing head consists of two cylindrical eater/sensor probes mounted on a short airfoil section mast. The front heater

is exposed directly to the airflow and impinging water droplets. The rear heater is housed within the inertia separator, which prevents any water droplets impinging on its surface. Both heaters are maintained at a constant electrical temperature by the electronic control module. The physical properties of the two probes and the recovery factor of the inertia separator give equal cooling to the two probes under dry air conditions; therefore, the same electrical power is required to make the temperature of the two probes equal. When supercooled water droplets are present, an increase in power is required by the front probe to maintain equality of temperature with the rear probe. The difference in power levels between the front and rear probes is, therefore, a fraction of the amount of water evaporated from the front probe in unit time. This power difference is processed by the electronic control module and presented on the cockpit indicator in terms of liquid water content ($gm/m^3$).

16. The icing surface temperature is obtained indirectly by a temperature sensor, which is part of the servo control system, maintaining the sensing head support mast at a temperature set above 0°C. This temperature signal is used to inhibit the indicator at the skin temperature at which no ice can form.

17. In order to check the complete system for correct functioning, a self-test facility is provided on the cockpit panel. When the self-test switch is activated, an electrical imbalance of the front probe temperature is created, which simulates cooling of the probe by water droplets. At the same time, the temperature sensor cut-out is disconnected to allow the check to be carried out in above freezing conditions. The resulting icing severity indicator deflection and warning lamp illumination indicate that both the sensing head and the control circuits are operational. Additionally, a facility is incorporated in the cockpit panel which provides illumination of a warning lamp when a predetermined scale reading is exceeded.

18. A USAAEFA-designed and fabricated visual ice accretion probe was installed on the copilot door below the window. This probe consisted of a 3.5-inch-wide airfoil section rigidly mounted on a support shaft. A 1.75-inch-long rod extended forward from the leading edge of the airfoil section and was marked in 1/4-inch increments. Using this probe, the rate and thickness of ice accretion was observed by the copilot during icing test flights.

Telemetry and Data Reduction System

19. A portable telemetry monitoring (TM) and data reduction system was fabricated to allow on-site data analysis. It consisted of e following equipment

Nems-Clark Type R10376 solid state TM receiver
EMR-Schlumberger Model 720 PCM bit synchronizer
EMR-Schlumberger Model 2731 PCM frame synchronizer
EMR-Schlumberger Model 713 programmable word selector
Hewlett-Packard Model 5245L electronic counter
Hewlett-packard Model 4204A oscillator
Tektronix Type 422 oscilloscope
Ampex Model PR 2200 tape transport
Clevite Model 9200 datum time code translator
Gould Model 260 brush recorders (two each)
EMR-Schlumberger Model 4150 proportional bandwidth

subcarrier discriminator (12 each)
EMR-Schlumberger Model 4150 constant bandwidth
subcarrier discriminator (12 each)
Bell and Howell datagraph Model 5-134 oscillograph

20. The TM receiver had a line-of-sight range of approximately 20 to 30 nautical miles and monitored signals on a 1435- to 1540-MHz band. The system converted these signals into a real time display of 12 PCM data channels on the brush recorders and six FM data channels on the oscillograph. The channels monitored during a flight were chosen by the project engineer from among any of the channels being recorded by the airborne magnetic tape system. The channels displayed could be changed at any time during the flight.

21. The package allowed for postflight strip-out of the flight tape. Each time the flight tape was run through the system 12 PCM and six FM channels could be processed. The electronic counter allowed actual PCM data counts to be compared with pen movements. The flight tape could be rerun until all desired data channels were stripped out. The system allowed for a tape search for a specified time slice and a digital display of the data.

# APPENDIX C-10

## INSTRUMENTATION AND SPECIAL EQUIPMENT

## AH-1G (Project No. 73-04-2)

### INSTRUMENTATION

#### Photopanel

1. The gunner instrument panel of the Alaska test helicopter was photographed by a 35mm camera which was mounted behind and over the right shoulder of the gunner. A film rate of one frame per second was used and the following cockpit instruments were photographed:

Airspeed indicator (ship's system)
Altimeter (ship's system)
Torque pressure gauge
Gas producer turbine speed indicator ($N_1$)
Main rotor speed indicator
Exhaust gas temperature indicator
Vertical speed indicator
Fuel quantity gauge

2. A photopanel was installed in the weapons bay of the test aircraft used during the Moses Lake tests. Photographs were taken by a 35mm camera at a rate of one frame per second and the following parameters were recorded:

Airspeed (ship's system)
Altitude (ship's system)
Engine torque
Gas producer speed ($N_1$)
Exhaust gas temperature
Main rotor speed
Outside air temperature
Engine inlet delta pressure
Vertical speed
Cyclic control position (longitudinal and lateral)
Directional control position
Collective control position
Event lights (pilot and copilot/gunner)
Time
Fuel count
Camera frame count

#### Analog Recorder

3. A Techni-Rite Model TR-666 six-channel analog recorder was installed in the ammunition bay of the Alaska test helicopter. The Model TR-666 is a direct-writing analog recorder. Writing is accomplished with the use of a heated stylus in contact with heat-sensitive paper. The following parameters were recorded:

Rosemount ice accretion analog signal
Pilot station vibration
    Vertical
    Lateral
Aircraft cg vibration
    Vertical
    Lateral
Tail rotor 90-degree gearbox vibration, longitudinal

Magnetic Tape System

4. An Ampex Model A700 1-inch magnetic tape recorder was installed in the aft battery compartment of the Moses Lake test helicopter. The following parameters were recorded and fuselage station (FS), vertical reference (water line (WL), and lateral reference (buttline (BL) are listed after the accelerometer locations.

Rosemount ice accretion analog signal
Rosemount icing severity signal
Pilot station deck vibration (GS 135.0, WL 55.1, BL 0)
    Vertical
    Longitudinal
    Lateral
Aircraft cg vibration (FS 197.1, WL 67.5, BL-9.5)
    Vertical
    Longitudinal
    Lateral
Tail rotor 90-degree gearbox vibration (FS 520.7, WL 114.7, BL 3.4)
    Vertical
    Longitudinal
    Lateral

Miscellaneous Instrumentation

5. Engine inlet plenum chamber static pressure was monitored inflight on both test aircraft. A sensitive altimeter was used to indicate changes in static pressure in the plenum chamber of the Alaska test aircraft, while a differential pressure gauge was used for this purpose on the Moses Lake test aircraft. On both aircraft, the delta pressure readout was shown on the gunner station instrument panel as well as the photopanel.

6. Cockpit communications were recorded with the use of small portable cassette tape recorders.

7. The following parameters were available from sensitive instrumentation installed in the CH-47C spray aircraft:

Airspeed
Altitude
Outside air total temperature
Dew point (Moses Lake tests only)
Water flow rate
Bleed air pressure

Test aircraft separation distance from spray aircraft

## SPECIAL EQUIPMENT

### Ice Accretion Indicator Probe

8. Visual ice accretion indicator probes were fabricated and mounted on the test aircraft. They were used to give additional visual cues of ice buildup on the fuselage of the helicopters. The probes were composed of small symmetrical airfoil sections (OH-6A tail rotor blade sections) with 3/16-inch diameter steel rods protruding outward from the leading edges at the center spans. The protruding rods were masked with 1/4-inch strips of contrasting colors which provided a comparison basis for visual ice measurement. Probes were mounted above the gunner position on both test aircraft and were visible from the gunner position throughout all phases of the tests. The test aircraft used in the Moses Lake tests had an additional probe located on the right side of the fuselage at the gunner station and approximately the same vertical station as the wing.

### Ice Detection System

9. A Rosemount ice detection system (Series No. 871) was used on each test aircraft to quantify icing rate and accretion while in the spray cloud. Each system consisted of a probe mounted on the sail of the aircraft, a cockpit indicator and an analog output, which was recorded on the magnetic tape data system.

10. The sensing element of the Rosemount ice detector is a tube that vibrates axially at a resonant frequency of about 40 kilohertz. Axial vibration is achieved by magnetostriction and amplitudes are on the order of microinches. When ice forms on the sensing element, a change in the resonant frequency occurs. The frequency change is noted by comparison with a fixed-frequency oscillator and the rate of frequency change is used to sense icing rate. Visual readout is from a meter calibrated for trace, light, moderate, and heavy icing rates. The system was calibrated by the manufacturer in a wind tunnel. The calibration information is shown in Table 1.

Table 1. Rosemount Icing Rate System

Wind Tunnel Liquid Water Content Calibration[1]

| Meter Indication | Measured Liquid Water Content ($gm/m^3$) |
| --- | --- |
| T (trace) | 0.09 |
| L (light) | 0.16 |
| M (moderate) | 0.29 |
| H (heavy) | 0.60 |

[1]Calibration for icing rate system, Model 512P, SN 4

APPENDIX C-11

INSTRUMENTATION AND SPECIAL EQUIPMENT

YAH-64 (Project No. 80-08)

GENERAL

1. In addition to standard aircraft instruments, calibrated instrumentation was installed on the test aircraft and maintained by Hughes Helicopter Incorporated. Data from the cockpit instrumentation were recorded on flight cards, and the specially installed instrumentation system recorded pulse code modulated (PCM) data on magnetic tape.

Pilot Panel

2. The pilot's panel instrumentation and test instrumentation are listed below:

Airspeed (ship's system)
Altitude (ship's system)
Altitude, radar (ship's system)
Rate of climb (ship's system)
Free air temperature (ship's system)
Rotor speed (ship's system and sensitive)
Engine torque (both engines, ship's system )
Engine turbine gas temperature (both engines, ship's system)
Engine gas generator speed (both engines, ship's system)
Engine power turbine speed (both engines, ship's system)
Stabilator position (ship's system)
Control positions
    Longitudinal
    Lateral
    Directional
    Collective
Icing rate (ship's system left engine inlet)
Icing rate (aspirated independent system mounted on aft cockpit overhead)

Full instrument landing system instrumentation
    Localizer
    Glide slope
    Marker beacon
Control panel for operation of data system to include event marker
Time code readout
Copilot/Gunner Panel

3. The copilot/gunner panel instrumentation and test instrumentation are listed below:

Airspeed (ship's system)
Altitude (ship's system)
Turn and slip indicator
Engine torque (both engines, ship's system)
Rotor speed (ship's system)

Engine power turbine speed (both engines, ship's system)
Total air temperature (Rosemount system with deice capability)
Decom unit (provide capability to read PCM counts for a give parameter)
Manual control panel for deice system
Control panel for operation of data system to include event marker
Time code readout
Camera controls

PCM Data Parameters

4. The following data were recorded on magnetic tape in PCM format:

- Airspeed
- Altitude
- Observed air temperature (Rosemount sensor)
- Observed air temperature (Rotor deice system)
- True airspeed longitudinal (pacer system)
- True airspeed lateral (pacer system)
- Observed air temperature (pacer system)
- Event markers (pilot and copilot)
- Indicated airspeed at ice detector location
- Engine torque (2)
- Engine fuel flow (2)
- Fuel temperature (2)
- Fuel used each engine (2)
- Engine turbine gas temperature (2)
- Engine gas generator speed (2)
- Main rotor speed
- Air temperature near deice control unit
- Control positions
  - Longitudinal
  - Lateral
  - Directional
  - Collective
- Attitudes
  - Pitch
  - Roll
  - Yaw
- Rates (station 200)
  - Pitch
  - Roll
  - Yaw
- Linear accelerations (station 200) near CG
  - Vertical
  - Lateral
  - Longitudinal
- Vibrations
  - 3 axis at pilot seat
  - 3 axis at copilot seat
  - 2 axis at tail rotor 90 degree gear box
    - Vertical
    - Lateral
  - Tail rotor mast structural attachment vertical

Stabilator incidence angle
Stabilator actuator current (2)
Icing severity (Deice system sensor)
Icing severity (Aspirated independent system)
Voltage
    Ship's system Bus 2
    Day side top window (TADS turret)
    Day side bottom window (TADS turret)
    Night side window (TADS turret)
    PNVS window
Rotor blade heater ON/OFF status
Current
    Generators Phase A (2)
    Windshield Phase A
    Blade Deice Phase A
Volt-time integral (Deice control system)
Windshield surface temperature (3) each panel
Engine inlet surface temperature (left)
Nose gearbox and cross shaft fairing surface temperature (left)
Cabin air temperatures
    TADS cooling inlet
    Left hand FAB inlet
    Right hand FAB inlet
    Pilot head level
    Copilot head level
    Pilot waist level
    Copilot waist level
    Pilot foot level
    Pilot ECS floor outlet
Surface temperatures
    Day side top window (TADS turret)
    Day side bottom window (TADS turret)
    Night side window (TADS turret)
    PNVS window
    Boresight modual window (TADS turret)
Engine bleed air pressure (2)
Lateral control actuator pistol rod force
Directional control actuator force
Tail rotor mast vertical bending
Tail rotor mast longitudinal bending
Time code
Voice track

Photographic

5. Three onboard cameras were used to document these icing tests. One high speed camera located on the right forward avionics bay (FAB) was synchronized with main rotor speed to photograph the main rotor advancing blade leading edge and lower surface. Another camera located on the top of the left wing tip photographed the tail rotor and horizontal stabilator. Another camera photographed the left engine inlet. During certainflights, the main rotor blade camera was mounted on the left FAB to document the hellfire deice sequence. Hand held cameras in the cockpit were used to document visible ice accretions as appropriate.

Helicopter Icing Spray System

6. In addition to standard aircraft instruments, calibrated instrumentation was installed aboard the CH-47C spray aircraft. This instrumentation was used to establish the desired test conditions during the icing flight and is listed below.

- Airspeed
- Altitude
- Free air temperature
- Dew point
- Water flow rate
- Bleed air pressure
- Radar distance (separation between test and spray aircraft)

APPENDIX C-12

INSTRUMENTATION AND SPECIAL EQUIPMENT

AH-1Q (Project No. 73-04-7)

INSTRUMENTATION

1. Standard aircraft instrumentation was used throughout the test. No special instrumentation was added.

SPECIAL EQUIPMENT

2. A USAAEFA-fabricated ice accretion measuring device and the TOW sighting unit turret position indicator were used to determine the quantity of ice and rate of accretion.

APPENDIX C-13

INSTRUMENTATION AND SPECIAL EQUIPMENT

BHT-412 (Project No. 80-10)

1. The BHT Model 412 helicopter was equipped with standard flight instrumentation and equipment. In addition to the standard equipment, the following equipment was installed for the deicing tests:

BHT 412-704-110, Main and Tail Rotor Deicing Kit
BHT 412-704-111, 30 KVA Alternator Kit
BHT 412-878-003, Windshield De-icing Kit
BHT 412-830-011, Teddington Hot Rod Ice Detector
BHT 212-961-065, Heated Pitot and Static Sources
127389, MK12A Leigh Ice Detector
Series 871, Rosemount Ice Detector
Model LWH, J-W Ice Detector

2. In addition to the above deicing equipment, the helicopter was also configured with instrumentation to record the blade temperatures and vibrations.

APPENDIX C-14

INSTRUMENTATION AND SPECIAL EQUIPMENT

UH-1H (Project No. 73-04-4, Part I)

INSTRUMENTATION

Photopanel

1. The pilot instrument panel was photographed with a 35mm camera. A film rate of one frame per second was used. The following parameters were recorded from standard aircraft instruments:

Airspeed (ship's system)
Altitude (ship's system)
Engine output shaft torque
Gas producer turbine speed ($N_1$)
Exhaust gas temperature
Main rotor speed
Vertical speed
Fuel quantity

Analog Recorder

2. A Techni-Rite Model TR-666 six-channel recorder was installed. The Model TR-666 is a direct-writing analog recorder. Writing is accomplished with the use of a heated stylus in contact with heat-sensitive paper. The following parameters were recorded:

Rosemount accretion analog signal
Pilot station vibration, vertical and lateral
Aircraft cg vibration, vertical and lateral
Tail rotor vibration, longitudinal

3. After flight 9, the following change was made: tail rotor lateral vibrations were recorded using the channel which had been used to record the Rosemount accretion analog signal.

MISCELLANEOUS INSTRUMENTATION

4. Engine inlet plenum chamber static pressure was measured using a sensitive altimeter. Outside air temperature was measured using a laboratory-type thermometer taped to the outside of the copilot windshield. Cockpit communications were recorded with the use of a small, portable cassette tape recorder.

APPENDIX C-15

INSTRUMENTATION AND SPECIAL EQUIPMENT

UH-1H (Project No. 74-31)

## INSTRUMENTATION

### Photopanel

1. A photopanel was used to record selected parameters on 35mm film. A film rate of one frame per second was used. The following parameters were recorded:

- Airspeed (ship's system)
- Altitude (ship's system)
- Engine output shaft torque
- Gas producer turbine speed ($N_1$)
- Exhaust gas temperature
- Main rotor speed
- Vertical speed
- Differential pressure in plenum chamber
- Total air temperature
- Fuel counter and flow rate
- Time
- Frame counter
- Event counter
- Even light
- Collective control position
- Lateral cyclic control position
- Longitudinal cyclic control position
- Directional control position

### Magnetic Tape System

2. An Ampex Model A700 one inch magnetic tape recorder was installed. The following parameters were recorded at the areas indicated:

- Vertical, lateral, and longitudinal vibrations:
  - Pilot station
  - Main rotor transmission area
  - Tail rotor 90 degree gearbox area
- Rosemount icing severity signal
- Rosemount ice accretion signal

APPENDIX C-16

INSTRUMENTATION AND SPECIAL EQUIPMENT

UH-1H (Project No. 74-13)

INSTRUMENTATION

1. The instrumentation that was installed on the test aircraft are listed in the subassemblies shown below. Selected items in the instrumentation package were supplied by USAAEFA and other Governmental agencies. All instrumentation was installed in the test aircraft by LCC and maintained by LCC.

Photopanel
Cockpit panel
FM magnetic tape recorder
Hub-mounted camera
Cathode ray tube (CRT) viewscopes
Main rotor slip rings
Tail rotor slip rings
Ice detection systems

2. Table 1 presents the test program measurement list and where each parameter was displayed and/or recorded automatically. Not all parameters were recorded on each flight. Recording limitations and various instrumentation component failures prevented simultaneous recording of all possible parameters. Those parameters that were considered critical to the safety and purpose of the flight were recorded.

PHOTOPANEL

3. A photopanel recording unit was used to collect data on selected test parameters. Table 1 shows the test parameters that were recorded by the photopanel. Thirty five millimeter film and a film rate of one frame per second was used to record the photopanel instrument readings.

MAGNETIC TAPE SYSTEM

4. An Ampex Model AR700 one inch magnetic tape recorder was installed in the test aircraft and used to record selected test parameters as shown in Table 1.

HUB-MOUNTED CAMERA

5. A 16mm rotor hub mounted camera was installed on top of the main rotor slip ring housing canister. The hub-mounted camera was designed to provide in-flight color photographic coverage of main rotor blade ice accumulation and shedding. The camera housing, camera lens, and camera housing window were electrically heated to prevent in-flight ice accumulation. The camera assembly was dynamically balanced for operating up to 450 rpm.

TEMPERATURE-SENSING TABS

6. Several visual temperature recording tabs were used on the instrumented main rotor blade to provide a history of maximum temperatures sensed by the external

surface of the erosion shield. Each temperature recording tab (Telatemp Model 110) has a dual Centigrade/Fahrenheit temperature scale that provides easy visual reference of maximum temperatures. The range of temperatures sensed is from 82 to 110 degrees on the Centigrade scale and from 180 to 230 degrees on the Fahrenheit scale. Each temperature recording pad is divided into six temperature-sensitive zones that discolor as a maximum zone temperature is exceeded.

## CATHODE RAY TUBE VIEWSCOPES

7. Five CRT viewscopes were installed in the test aircraft to provide onboard real time in-flight monitoring of selected test parameters. A qualified flight test engineer was positioned in the test aircraft to monitor the CRT viewscopes while inflight. The following parameters were monitored on the CRT viewscopes.

a. Main rotor pitch link loads.
b. Main rotor flapping loads at blade station 35.
c. Main rotor chordwise bending loads at blade station 35.
d. Tail rotor pitch link loads.
e. Tail rotor chordwise bending loads.

## SLIP RING ASSEMBLY

8. The main rotor slip rings are enclosed in a canister assembly mounted on top of the rotor hub and attached to the same brackets that provide the trunnion mounting for the stabilizer bar. These brackets were replaced with new ones that incorporated flanges on top to provide a mounting surface for the slip ring assembly. The slip ring assembly included the slip rings for both the deicing system and instrumentation, the heater distribution switch, the instrumentation voltage--controlled oscillators (VCO) and their power supply, two terminal strips, all of the related wiring for these components, and an environmentally sealed housing. The mass distribution within this assembly was not symmetrical, so the entire assembly was dynamically precision-balanced for operating speeds of up to 450 rpm.

Table 1. Test Parameters

| | Magnetic Tape | Photopanel | Cockpit |
|---|---|---|---|
| Civil time | | X | X |
| Time code | X | | X |
| Airspeed | X | X | X |
| Altitude | X | X | X |
| Engine torque | | X | X |
| Gas producer speed ($N_1$) | | X | X |
| Exhaust gas temperature | | X | X |
| Air temperature (total and static) | X | X | X |
| Collective pitch position | X | | X |
| Collective force | X | | |
| Pilot windshield voltage | X | | X |
| Pilot windshield thermocouples | X | | |
| Copilot windshield voltage | X | | X |
| Copilot windshield thermocouples | X | | |
| Engine plenum delta pressure | X | | X |
| AC generator voltage | X | | X |
| AC generator amperage | X | | X |
| AC generator inlet air temperature | | | X |
| AC generator exhaust air temperature | | | X |
| AC generator accelerometer | X | | |
| Main rotor voltage | X | | |
| Main rotor strain gages | X | | |
| Main rotor pitch link strain gage | X | | |
| Main rotor thermocouples | X | | |
| Main rotor PIP | X | | |
| Tail rotor voltage | X | | |
| Tail rotor strain gages | X | | |
| Tail rotor pitch link strain gages | X | | |
| Tail rotor thermocouples | X | | |
| Tail rotor PIP | X | | |
| Main transmission accelerometer | X | | |
| 90-degree gearbox accelerometer | X | | |
| Center of gravity accelerometer | X | | |
| Pilot floor-mounted accelerometer | X | | |
| Pilot seat pad-mounted accelerometer | X | | |
| Rosemount icing severity | X | | X |
| Leigh icing severity | X | | X |
| Variac voltage | | | X |
| Battery temperature | | | X |
| Event marker | X | X | |
| Fuel quantity | | | X |
| Hub camera burst counter | | | X |
| Voice recorder | | | X |

## APPENDIX C-17

## INSTRUMENTATION AND SPECIAL EQUIPMENT

## UH-1H (Project No. 77-30)

### INSTRUMENTATION

1. Instrumentation was installed in the test aircraft by USAAEFA personnel prior to the start of the icing test program. Calibrated test indicators were installed in place of an in addition to normal cockpit flight indicators. Special test instrumentation was located in the cockpit to monitor the following parameters:

Pilot Panel

Airspeed
Altitude

Copilot/Engineer Panel

Airspeed
Altitude
Rotor speed
Engine torque pressure
Outside air temperature

2. An FM data recording system was used to record the following:

Pilot collective control position
Engine torque pressure
Pilot station vibration - triaxial accelerometer (WL 22, BL 22, FS 60)
Copilot station vibration - triaxial accelerometer (WL 22, BL 22, FS 50)
Aircraft cg vibration - triaxial accelerometer (WL 22, BL 0, FS 131)

3. The following parameters were hand-recorded from test instrumentation installed in the CH-47C spray aircraft:

Airspeed
Altitude
Outside air temperature
Dew point
Water flow rate (spray system)
Bleed air pressure (to the spray system)
Test aircraft separation distance from aircraft

APPENDIX C-18

# INSTRUMENTATION AND SPECIAL EQUIPMENT

## UH-1H (Project Nos. 78-21 and 78-21-2)

### INSTRUMENTATION

1. The test instrumentation was installed, calibrated, and maintained by BHT. Digital and analog data were obtained from calibrated instrumentation and were recorded on oscillographs and/or displayed in the cockpit.

2. In addition to standard ship's instruments, the following parameters were displayed on calibrated test instruments in the cockpit or on the engineer's console:

- Fuel flow
- Fuel used
- Engine inlet screen differential pressure
- Engine torque
- Pilot's windshield temperatures (8)
- Outside air temperature at right windshield
- Leigh ice detector bleed air pressure
- Leigh ice detector bleed air temperature
- Rosemount ice detector bleed air pressure
- Rosemount ice detector bleed air temperature

3. The following parameters were recorded on oscillographs:

- Control position
    - Longitudinal
    - Lateral
    - Directional
    - Collective
- Engine torque
- Fuel flow
- Engine inlet screen differential pressure
- Aircraft attitude
    - Pitch
    - Roll
    - Yaw
- Pilot seat vertical acceleration
- Transmission lateral acceleration
- Ninety degree gearbox vertical acceleration
- Center of gravity vertical acceleration
- Main and tail rotor azimuth
- Main rotor beam bending loads
- Main rotor pitchlink axial loads
- Tail rotor beam bending loads
- Tail rotor chord bending loads
- Tail rotor pitch link axial loads
- Main rotor temperatures at the following stations:
    - Station 257.11 (zone 1)

Station 201.76 (zone 2)
Station 110 (zone 4) (6 chordwise points)
Station 84.5 (zone 5, steel)
Station 84.5 (zone 5, aluminum)
Station 55 (zone 6)

Tail rotor temperatures at the following stations:
Station 35, lower
Station 22, lower

Outside air temperature:
Rosemount (Kit A)
Lewis flush mounted cabin-roof
Tail fin

Main rotor heating signal voltage
Main rotor heating signal event
Main rotor AC phase voltage
Tail rotor AC phase voltage
Leigh liquid water content
Leigh icing signal
Leigh IRU last sum of ice accumulator
Rosemount icing severity
Rosemount analog icing signal
Rosemount probe heat event
Copilot windshield overtemp sensor temperature

## SPECIAL EQUIPMENT

### Hub-Mounted Camera

4. A 16mm movie camera was installed on top of the main rotor slip ring housing canister. The hub-mounted camera was designed to provide in-flight color photographic coverage of main rotor blade ice accumulation and shedding. The camera lens was electrically heated to prevent in-flight ice accumulation.

### Ice Accretion Indicator Probe

5. An ice accretion indicator probe was mounted on the test aircraft to give the copilot a visual cue to ice buildup on the helicopter. It was composed of a small symmetrical air foil (OH-6A tail rotor blade section) with a 3/16-inch diameter steel rod protruding 1-1/2-inches out from the leading edge at the center. The protruding rod was painted with multi-colored 0.2-inch strips to provide a reference for ice thickness estimation. The unit was mounted on the copilot's door facing forward.

### Leigh MK 12 Ice Detector

6. For natural icing tests in Syracuse, an additional ice detector and cockpit LWC indicator were installed on the test aircraft. The ice detector unit, a Leigh Instruments, Ltd. MK XII (IDU-3) is an infrared occlusion type detector identical in principle of operation to the MK 10-3D. The display meter used to indicate LWC is a Western Model 1822 with a 2-inch diameter face.

APPENDIX C-19

INSTRUMENTATION AND SPECIAL EQUIPMENT

UH-1H (Project No. 79-02)

INSTRUMENTATION

1. The test instrumentation was installed, calibrated, and maintained by USAAEFA. Digital and analog data were obtained from calibrated instrumentation and were recorded on magnetic tape and/or displayed in the cockpit. The digital instrumentation system consisted of various transducers, signal condition units, an eight-bit PCM encoder, and an Ampex AR 700 tape recorder.

Time correlation was accomplished with a pilot/engineer event switch and onboard recorded and displayed Inter-Range Instrumentation Group (IRIG) B time. Analog data were recorded on one track of the AR 700 recorder through the use of a voltage control oscillator (VCO). Various specialized test indicators displayed data to the crew continuously during the flight.

2. In addition to standard ship's instruments, the following parameters were displayed on calibrated test instruments in the cockpit:

Airspeed (ship's)
Altitude (ship's)
Fuel flow
Fuel used
Engine torque
Engine inlet screen differential pressure
Main rotor speed
Rosemount OAT
Lewis OAT (Vertical tail fin)
Cambridge dew point temperature
Rosemount LWC
Leigh Mark 10 LWC
Leigh Mark 10 IRC
Leigh ice detector bleed air pressure
Rosemount ice detector bleed air pressure

3. The following parameters were recorded on magnetic tape:

PCM Parameters

Control position
- Longitudinal
- Lateral
- Directional
- Collective

Engine torque
Fuel flow
Fuel used
Airspeed (ship's)
Altitude (ship's)
Main rotor speed

Engine inlet screen differential pressure
Aircraft attitude:
  Pitch
  Roll
  Yaw
Aircraft rates
  Pitch
  Roll
  Yaw
Outside air temperature
Rosemount LWC
Leigh Mark 10 LWC
Lewis OAT (vertical tail fin)
Cambridge dew point temperature
CG normal acceleration
Leigh Mark 10 IRU present sum
Leigh Mark 10 IRU last sum

FM Parameters

CG lateral acceleration
Pilot seat acceleration
  Lateral
  Vertical
Main rotor pitch link axial load
Tail rotor pitch link axial load

## SPECIAL EQUIPMENT

### Dew Point Meter

4. A Cambridge Model 137 chilled mirror dew point hygrometer is located on the cabin roof. This device samples airflow and indicates a corresponding dew point temperature to a cockpit display and to the PCM tape system.

### Hub-Mounted Camera

5. A 16mm movie camera was installed on top of the main rotor slip ring housing canister. The hub-mounted camera was designed to provide in-flight color photographic coverage of main rotor blade ice accumulation and shedding. The camera lens was electrically heated to prevent in-flight ice accumulation.

### Ice Accretion Indicator Probe

6. A visual ice accretion indicator was mounted on the test aircraft to give the copilot a visual cue of ice buildup on the helicopter. It was composed of a small symmetrical air foil (OH-6A tail rotor blade section) with a 3/16-inch diameter steel rod protruding 1 1/2-inches out from the leading edge at the center. The protruding rod was painted with multi-colored 0.2-inch stripes to provide a reference for ice thickness estimation. The unit was mounted on the copilot's door facing forward.

Meteorological Research Incorporated (MRI) Equipment

7. The test objectives requiring cloud parameter data (LWC and droplet size distribution) were obtained through MRI instrumentation. The following equipment was installed on the test aircraft: an axially scattering probe (ASP), a cloud particle spectrometer (CPS), and associated recording equipment.

8. The ASP sizes particles by measuring the amount of light scattered into the collecting optics apperture during particle interaction through a focused laser beam. The signal pulses are AC coupled to a pulse height detector which compares their maximum amplitude with a reference voltage derived from a separate measurement of the DC light signal illuminating particles. The system is capable of sizing particles from two to 30-microns diameter having velocities from 10 to 125 m/sec (20 to 240 kts).

9. In the CPS, particles are sized using a linear array of photodiodes to sense the shadowing of array elements by particles passing through its field-of-view. Particles are illuminated by a helium-neon laser. As shadowing of each photodiode element is dark enough, a flip-flop memory element is set. The particle size is determined by the number of elements set by a particle's passage, the size of each array element, and the magnification of the optical system.

10. Two different CPS probes were used during this evaluation. One probe contained 24 active photodiode elements capable of sizing into 15 size channels with a magnification set for a size range of 20 to 300 microns. The other probe contained 20 photodiode elements capable of sizing into 15 size channels with a magnification set for a size range of 140 to 2100 microns.

APPENDIX C-20

INSTRUMENTATION AND SPECIAL EQUIPMENT

UH-1H (Project No. 80-13)

## INSTRUMENTATION

1. The test instrumentation was installed, calibrated, and maintained by U.S. Army Aviation Engineering Flight Activity (USAAEFA). Digital and analog data were obtained calibrated instrumentation and were recorded on magnetic tape and/or displayed in the cockpit. The digital instrumentation system consisted of various transducers, signal condition units, an eight-bit pulse code modulation (PCM) encoder, and an Ampex AR 700 tape recorder. Time correlation was accomplished with a pilot/engineer event switch and onboard recorded and displayed Inter-Range Instrumentation Group B time. Analog data were recorded on one track of the AR 700 recorder through the use of a voltage control oscillator. Various specialized test indicators displayed data to the crew continuously during the flight.

2. In addition to standard ship's instruments, the following parameters were displayed on calibrated test instruments in the cockpit:

Pilot's Panel

Airspeed (ship's)
Altitude (ship's)
Fuel flow
Fuel used
Engine torque
Engine inlet screen differential pressure
Rosemount outside air temperature (OAT)
Rosemount liquid water content (LWC)
Leigh Mark 12 LWC
Leigh Mark 12 integrating rate unit (IRU)

Engineer's Panel

Main rotor speed
Leigh Mark 10 LWC
Leigh Mark 10 IRU
Vertical tail fin OAT
Cambridge dew point temperature
Leigh ice detector bleed air pressure
Rosemount ice detector bleed air pressure

3. The following parameters were recorded on magnetic tape.

PCM Parameters

Control position:
  Longitudinal
  Lateral
  Directional

Collective
Engine torque
Fuel flow
Fuel used
Airspeed (ship's)
Altitude (ship's)
Main rotor speed
Engine inlet screen differential pressure
Aircraft attitude:
Pitch
Roll
Yaw
Aircraft rates:
Pitch
Roll
Yaw
Oat
Rosemount LWC
Leigh Mark 10 LWC
Lewis OAT (vertical tail fin)
Cambridge dew point temperature
Normal acceleration center of gravity
Leigh Mark 10 IRU present sum
Leigh Mark 10 IRU last sum
Leigh Mark 12 IRU ice units
Main rotor temperatures at the following stations:
Station 257.11 (zone 10)
Station 110 (zone 4)
Station 55 (zone 6)

Frequency Modulated

CG lateral acceleration
Pilot seat acceleration
Lateral
Vertical
Main rotor pitch link axial load
Tail rotor pitch link axial load

## SPECIAL EQUIPMENT

### Dew Point Meter

4. A Cambridge Model 137 chilled mirror dew point hygrometer was located on the left hinged panel door. This device sampled airflow and indicated a corresponding dew point temperature to a cockpit display and to the PCM tape system.

### Strobe Camera

5. A 16mm stop action camera was mounted on the inside of the right hinged panel door. A strobe light was incorporated in the design to allow photographing a single main rotor blade throughout the flight. This strobe camera was intended to provide in-flight photographic coverage to quantify main rotor blade ice accumulation and shedding.

APPENDIX C-21

INSTRUMENTATION AND SPECIAL EQUIPMENT

JUH-1H (Project No. 81-11)

INSTRUMENTATION

1. The test instrumentation was installed, calibrated, and maintained by the U.S. Army Aviation Engineering Flight Activity (USAAEFA), except the load strain gages which were installed by Bell Helicopter Textron (BHT). Digital and analog data were obtained from calibrated instrumentation and were recorded on magnetic tape and/or displayed in the cockpit. The digital instrumentation system consisted of various transducers, signal condition units, and eight-bit pulse code modulation (PCM) encoder, and an Ampex AR 700 tape recorder.

2. In addition to standard ship's instruments, the following parameters were displayed on calibrated test instruments and recorded manually in the cockpit:

Pilot's Panel

Airspeed (ship's)
Altitude (ship's)
Fuel flow
Fuel used
Engine torque
Engine inlet screen differential pressure
Rosemount outside air temperature (OAT)
Rosemount liquid water content (LWC)
Tether cable tension

Engineer's Panel

Main rotor speed
Ejector control valve regulated pressure.
Vacuum/pressure of the deicer boot
Engine bleed air temperature at engine deck
Engine bleed air temperature at the ejector control valve
Engine bleed air temperature at the regulator-reliever/shut-off valve
Main rotor blade chord bending at station 192
Main rotor hub beam bending at station 6.3
Main rotor hub chord bending at station 6.3

3. The following parameters were recorded on magnetic tape.

PCM Parameters

Control position
- Longitudinal
- Lateral
- Directional
- Collective

Engine torque

Fuel flow
Fuel used
Airspeed (ship's)
Altitude (ship's)
Main rotor speed
Bleed Air Press (pressure/vacuum)
Bleed Air Press for PBDS
Aircraft attitude
    Pitch
    Roll
    Yaw
Aircraft rates
    Pitch
    Roll
    Yaw
Outside air temperature
Center of gravity normal acceleration
Tether cable tension
Pilot seat vertical vibration
Main rotor blade pitch angle (red blade)
Main rotor blade flapping angle (red blade)
Main rotor azimuth
Main rotor mast torque
Main rotor mast bending perpendicular
Main rotor blade beam and chord bending at the following stations
    Station 35
    Station 84
    Station 150
    Station 192
    Station 234

4. The following frequency modulated parameters were recorded and telemetered to a ground station for real-time safety of flight monitoring.

Main rotor pitch link axial force
Main rotor mast bending parallel
Main rotor blade beam bending at station 192

APPENDIX C-22

INSTRUMENTATION AND SPECIAL EQUIPMENT

UH-1H (Project No. 82-12)

INSTRUMENTATION

1. Except for the main rotor blade load instrumentation, the test instrumentation was installed, calibrated, and maintained by U.S. Army Aviation Engineering Flight Activity (USAAEFA) personnel. Digital and analog data were obtained from calibrated instrumentation and were recorded on magnetic tape and/or displayed in the cockpit. Recorded data were taken at ten samples per second, and five Hz filters were used. Blade and mast instrumentation was installed by Bell Helicopter Textron.

2. The test instruments displayed in the cockpit are listed below.

Main rotor speed
Engine torque
Pressure altitude
Engine inlet differential pressure
Load cell
Outside air temperature
Fuel used
Control positions (4)
Time of day
Run number

3. Data parameters recorded onboard the aircraft in PCM format are listed below.

Time of day
Event
Run number
Main rotor speed
Main rotor torque
Engine torque
Turbine speed
Compressor speed
Liner acceleration
Fuel used
Magnetic heading
Pressure altitude
Outside air temperature
Measured gas temperature
Control positions (4)
Fuel temperature
Roll attitude
Pitch attitude
Attitude rates (3)
Blade flapping
Blade pitch

Pitch link load
Mast parallel bending
Mast perpendicular bending
Hub beam and chord bending
Blade beam and chord bending (B.S. 35)
Blade beam and chord bending (B.S. 84)
Blade beam and chord bending (B.S. 150)
Blade beam and chord bending (B.S. 192)
Blade beam and chord bending (B.S. 234)

4. The following were recorded on the ground.

Ambient temperature
Ambient pressure
Wind speed and direction
Water flow rate (spray rig)
Steam and water pressures (spray rig)

APPENDIX C-23

INSTRUMENTATION AND SPECIAL EQUIPMENT

UH-1H (Project No. 83-23)

## INSTRUMENTATION

1. Except for the main rotor blade load instrumentation, the test instrumentation was installed, calibrated, and maintained by U.S. Army Aviation Engineering Flight Activity personnel. Digital and analog data were obtained from calibrated instrumentation and were recorded on magnetic tape and/or displayed in the cockpit. Recorded data were taken at 474 samples per second. Blade and mast instrumentation was installed by Bell Helicopter Textron.

2. The test instruments displayed in the cockpit are listed below.

Main rotor speed
Engine torque
Pressure altitude
Engine inlet differential pressure
Outside air temperature
Fuel used
Control positions (4)
Airspeed
Altitude
Time of day
Run number

3. Data parameters recorded onboard the aircraft in PCM format are listed below.

Time of day
Event
Run number
Main rotor speed
Main rotor torque
Engine torque
Turbine speed
Compressor speed
Linear acceleration (3)
Fuel used
Magnetic heading
Pressure altitude
Outside air temperature
Measured gas temperature
Control positions (4)
Fuel temperature
Roll attitude
Pitch attitude
Attitude rates (3)
Blade flapping
Blade pitch
Pitch link load

- Airspeed
- Altitude
- Mast parallel bending
- Mast perpendicular bending
- Hub beam and chord bending
- Blade beam and chord bending (Blade Station 35)
- Blade beam and chord bending (Blade Station 84)
- Blade beam and chord bending (Blade Station 150)
- Blade beam and chord bending (Blade Station 192)
- Blade beam and chord bending (Blade Station 234)

4. The boom airspeed system was calibrated using a trailing bomb. The correction was converted to a delta static pressure, and altitude was also corrected.

APPENDIX C-24

INSTRUMENTATION AND SPECIAL EQUIPMENT

UH-60A (Project No. 81-18)

## INSTRUMENTATION

1. The test instrumentation was installed, calibrated, and maintained by USAAEFA personnel. Data were measured with calibrated instrumentation and displayed or recorded as indicated below. The pulse code modulation (PCM) sampling rate was 200 samples per second.

Pilot's Panel

Liquid water content (Rosemount Probe)

Copilot Panel

Airspeed (ship's system)
Pressure altitude (ship's system)

Engineer Panel

Instrumentation controls
Free air temperature
Time code display
Run number

Digital (PCM) Data Parameters

Airspeed (ship's system)
Altitude (ship's system)
Total air temperature
Rotor speed
Gas generator speed* Fuel used*
Engine fuel flow*
Engine output shaft torque*
Engine turbine gas temperature*
Control position
- Longitudinal cyclic
- Lateral cyclic
- Directional
- Collective

Aircraft attitude
- Pitch
- Roll
- Yaw

Icing rate (Rosemount)
Time of day
Run Number
Pilot and engineer event pulse
Vibration (accelerometers)

Pilot station vertical
Pilot station lateral
Pilot station longitudinal
Aircraft cg vertical
Aircraft cg lateral
Aircraft cg longitudinal
Tail rotor gearbox lateral
Tail rotor gearbox longitudinal

Forward longitudinal main transmission stationary star load
*Both engines

SPECIAL EQUIPMENT

Camera System

2. A 16mm high-speed hand-held motion picture camera was located on board the chase and HISS aircraft and was used to document the test aircraft both in the spray cloud and after exit from icing encounters. Additionally, 35mm color slide and color still camera were used for documentation both in the air and on the ground following icing flights.

Visual Ice Accretion Probe

3. A visual ice accretion indicator probe was fabricated and installed on the test aircraft. It was used to give additional visual cues of ice buildup on the aircraft fuselage. The probe was composed of a small symmetrical airfoil section (OH-6A tail rotor blade section) with a 3/16 inch diameter steel rod protruding forward from the leading edge at the center span. The protruding rod was painted with 1/4 inch stripes of contrasting colors which provide a comparison basis for visual ice measurements. The probe was mounted on the left cockpit door just below the window.

Cloud Sampling Equipment

4. An instrumentation package was installed on the U-21A chase/scout aircraft and used to document both the artificial and natural icing conditions in which the test aircraft flew. This equipment consisted of two laser nephelometers (a forward scattering spectrometer probe (ESSP) and an optical array probe (OAP), Leigh MK-10 ice detector, calibrated outside air temperature indicator and a dew point hygrometer. The cloud sample data was presented in near real time to the particle measuring system operator on board the U-21 and also stored on magnetic tape.

APPENDIX C-25

INSTRUMENTATION AND SPECIAL EQUIPMENT

YEH-60A (Project No. 83-21)

## SPECIAL EQUIPMENT

### Camera Systems

1. Two video cameras were located on the test aircraft to monitor and document accretion characteristics on the #2 and #3 Direction Finding (DF) dipole antennae and the Electronic Countermeasures (ECM) antenna (photos 1 and 2) Each camera was controlled and powered by a separate battery powered recorder. A switch enables the engineer to select which camera output was displayed on the single color video monitor mounted at the ECM operator's position. Additionally, a video camera, a 16mm camera, and a 16mm motion picture camera were located on board the chase and HISS aircraft and were used to document the test aircraft both in the spray cloud and after exit from icing encounters. Single lens reflex and 35mm color cameras were used for still photo documentation (color prints and slides), both in the air and on the ground, following icing flights.

### Visual Ice Accretion Probe

2. A visual ice accretion indicator probe was fabricated and installed on the test aircraft. It was used to give additional visual cues of ice buildup on the aircraft fuselage. The probe was composed of a small symmetrical airfoil section (OH-6A tail rotor blade sections) with 3/16 inch diameter steel rod protruding outward from the leading edge of the center span. The protruding rod was painted with 1/4 inch stripes of contrasting colors which provided a means of measuring ice accumulation. The probe was mounted on the left cockpit door just below the window.

### Cloud Sampling Equipment

3. Icing conditions were measured in both the natural and artificial environments, USAAEFA employs a U-21 fixed-wing aircraft, U.S. Army S/N 66-18008. This aircraft was equipped with the following equipment: A Particle Measuring System (PMS), forward scattering spectrometer probe (model FSSP-100), a PMS optical array cloud droplet spectrometer probe (model OAP-200X), Rosemount OAT sensor and display Cambridge model 137 chilled mirror dew point hygrometer and display, Leigh MK-10 ice detector unit with digital display, and a Small Intelligent Icing Data System (SIIDS).

4. The FSSP-100 sizes particles by measuring the amount of light scattered into the collecting optics aperture during particle interaction through a focused helium-neon high order, multimode laser beam. The signal pulses are alternating current coupled to a pulse height analyzer which compares their maximum amplitude with a reference voltage derived from a separate measurement of the direct current light signal illuminating the particles. The output of the pulse height analyzer is encoded to give the particle size in binary code. The probe is set up to size particles from two to 47 microns having velocities between 20 and 125 m/sec (39 to 243 knots).

5. The OAP-200X sizes using a linear array of photodiodes to sense the shadowing of array elements by particles passing through its field-of-view. Particles are illuminated by a helium-neon laser and imaged as shadowgraphs on the photodiode array. If the shadowing of each photodiode element is dark enough, a flip-flop element is set. The particle size is determined by the number of elements set by a particle's passage, the size of each array element, and the magnification of the optical system. This probe contains 24 active photodiode elements capable of sizing into 15 size channels with a magnification set for a size range of 20 to 300 microns.

6. The SIIDS is a compact data acquisition system designed and programmed specifically for icing studies. It consists of four main components: a microprocessor, Techtran data cassette recorder, Axiom printer, and an operator control panel. The SIIDS has three operational modes: (1) data acquisition, in which averaged raw data are recorded on cassette tape and averaged engineering units are displayed on the printer, (2) a playback mode in which raw averaged data read from the cassette are converted to average engineering units which are displayed on the printer, (3) monitor mode used to set the calendar clock and alter programmed constants. During data acquisition, the operator may select an averaging period of 1/2, 1, 2, 5, or 10 seconds.

7. The following parameters are displayed on the SIIDS printer in engineering units.

a. Calendar: year, month, day, hour, minute, and second.

b. Pressure altitude (feet).

c. Airspeed (knots).

d. Outside air temperature (°C).

e. Dew point (C°).

f. Total liquid water content observed by the FSSP ($g/m^3$).

g. Total liquid water content observed by both the FSSP and OAP ($g/m^3$).

h. Median volumetric diameter (m) .

i. Amount of liquid water content observed for each channel (total 30) of both probes ($g/m^3$).

## APPENDIX C-26

## INTRUMENTATION AND SPECIAL EQUIPMENT

## UH-60 (Project No. 83-22)

### SPECIAL EQUIPMENT

#### Camera Systems

1. A video camera and a 16mm motion picture camera were located onboard the chase and Helicopter Icing Spray System (HISS) aircraft and were used to document the test aircraft both in the spray cloud and after exit from icing encounters. Single lens reflex 35mm cameras were used for still photo (color prints and slides) documentation both in the air and on the ground following icing flights.

#### Cloud Sampling Equipment

2. For cloud measurements in both the natural and artificial environments, USAAEFA employs a UH-21A fixed-wing aircraft, U.S. Army S/N 66-18008, equipped with a cloud measurement package. This package consists of the following equipment: a Particle Measuring System (PMS), forward scattering spectrometer probe (model FSSP-100), a PMS optical array cloud droplet spectrometer probe (model OAP-200X), Rosemount outside air temperature sensor and display, Cambridge model 137 chilled mirror dew point hygrometer and display, Leigh Mk 10 ice detector unit with digital display, cloud technology ice detector unit, and a Small Intelligent Icing Data System (SIIDS).

3. The FSSP-100 sizes particles by measuring the amount of light scattered into the collecting optics aperture during particle interaction through a focused helium-neon high order, multimode laser beam. The signal pulses are alternating current coupled to a pulse height analyzer which compares their maximum amplitude with a reference voltage derived from a separate measurement of the direct current light signal illuminating the particles. The output of the pulse height analyzer is encoded to give the particle size in binary code. The probe is set up to size particles from 2 to 47 microns having velocities between 20 and 125 m/sec (39 to 243 knots).

4. The OAP-200X sizes using a linear array of photodiodes to sense the shadowing of array elements by particles passing through its field-of-view. Particles are illuminated by a helium-neon laser and imaged as shadowgraphs on the photodiode array. If the shadowing of each photodiode element is dark enough, a flip-flop element is set. The particle size is determined by the number of elements set by a particle's passage, the size of each array element, and the magnification of the optical system. This probe contains 24 active photodiode elements capable of sizing into 15 size channels with a magnification set for a size range of 20 to 300 microns.

5. The SIIDS is a compact data acquisition system designed and programmed specifically for icing studies. It consists of four main components: a microprocessor, Techtran data cassette recorder, Axiom printer, and an operator control panel. The SIIDS has three operational modes: (1) data acquisition in which averaged raw data are recorded on cassette tape and averaged

engineering units are displayed on the printer, (2) a playback mode in which raw averaged data read from the cassette are converted to average engineering units which are displayed on the printer, (3) monitor mode used to set the calendar clock and alter programmed constants. During data acquisition, the operator may select an averaging period of 1/2, 1, 2, 5, or 10 seconds.

6. The following parameters are displayed on the SIIDS printer in engineering units.

Calendar: year, month, day, hour, minute, and second.

Pressure altitude (feet).

Airspeed (knots).

Outside air temperature (°C).

Dew point (°C).

Total liquid water content observed by the FSSP ($g/m^3$).

Total liquid water content observed by both the FSSP and OAP ($gm/m^3$).

Median volumetric diameter (m).

Amount of liquid water content observed for each channel (total 30) of both probes ($g/m^3$).

## APPENDIX D

## DISTRIBUTION LIST

Civil Aviation Authority (5)
Aviation House
129 Kingsway
London WC2B 6NN England

Embassy of Australia (1)
Civil Air Attache
1601 Mass. Ave. NW
Washington, DC 20036

Scientific & Tech. Info FAC (1)
ATTN: NASA Rep.
P.O. Box 8757 BWI Airport
Baltimore, MD 21240

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Service Dept Institute of
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Civil Air Attache ATS
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Washington, DC 20008

Director DuCentre Exp DE LA (1)
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ADL-1 (1)
ALG-300 (1)
ACT-8 (1)

Mr. Marlin Breer
Boeing Wichita Company
3801 South Oliver
K-7615
Wichita, KA 67210

Mr. Marshall O. Burquest
FAA; ANM-172W
Airframe Section
15000 Aviation Boulevard
Hawthorne, CA 90261

Mr. Marvin Beene
FAA; ACE-120W
Airframe Branch
1801 Airport Road
Wichita, KS 67209

Mr. Nat Moore
Cessna-Wallace Aircraft Di
P.O. Box 7704
Wichita
KS 67277

Mr. Pat Perrotta
FAA; ANE-174
Propulsion Branch
181 South Franklin Avenue
Valley Stream, NY 11581

Mr. Paul Balfe
FAA; ANE-156
Flight Test Branch
12 New England Exec. Park
Burlington, MA 01803

Mr. Ralph Rissmiller, Jr.
FAA; ACE-130W
Systems & Equipment Branch
1801 Airport Road
Wichita, KS 67209

Mr. Raymond J. Borowski
FAA; ANE-170
New York ACO
181 South Franklin Avenue
Valley Stream, NY 11581

Mr. Richard Adams
FAA; AWS-104
Office of Airworthiness
800 Independence Ave., SW
Washington, DC 20591

Mr. Richard B. Davis
FAA; ACE-120A
Airframe Branch
1075 Innerloop Road
College Park, GA 30337

Mr. Robert E. Follensbee
FAA; ANM-140L
Propulsion Brandh
4344 Donald Douglas Drive
Long Beach, CA 90808

Mr. Robert E. Guyotte
FAA; ANE-142
GA Engine Branch
12 New England Exec. Park
Burlington, MA 01803

Mr. Robert J. Huhn
FAA; ANM-150S
Foreign Certification Br.
17900 Pacific Highway S.
Seattle, WA 98168

Mr. Robert L. Klapprott
FAA; ACE-130W
Systems & Equipment Branch
1801 Airport Road
Wichita, KS 67209

Mr. Robert McKnight
NASA Lewis Research Center
21000 Brook Park Road
Cleveland
OH 44135

Mr. Robert Miller
FAA; ACE-130A
Systems Branch
1075 Innerloop Road
College Park, GA 30337

Mr. David P. West
FAA; ACE-160A
Flight Test Branch
1075 Innerloop Road
College Park, GA 30337

Mr. Donald Michal
FAA; ACE-130C
Systems & Equipment Branch
2300 East Devon Avenue
Des Plaines, IL 60018

Mr. Frank D. Melton
FAA; ANM-160S
Flight Test Branch
17900 Pacific Highway S.
Seattle, WA 98168

Mr. Warren Green
FAA-Capital City GADO
Capital City Airport
New Cumberland
PA 17070

Mr. William Norton
FAA; ACE-160C
Flight Test Branch
2300 East Devon Avenue
Des Plaines, IL 60018

Mr. William von Brockdorff
FAA; ANM-120L
Airframe Branch
4344 Donald Douglas Drive
Long Beach, CA 90808

Mr. Woodford R. Boyce
FAA; ANM-170D
Denver ACO
10455 East 25th Avenue
Aurora, CO 80010

Mr. Dayton O. Curtis
FAA; ANM-170A
Anchorage ACO
P.O. Box 14
Anchorage, AK 99513

Mr. Edward W. Maila
FAA; ANE-152
Airframe Branch
12 New England Exec. Park
Burlington, MA 01803

Mr. Fred G. Jones
FAA; ACE-140A
Propulsion Branch
1075 Innerloop Road
College Park, GA 30337

Mr. Wayne Barbini
FAA; AWS-110
Heli. Policy & Proc. Staff
P.O. Box 1689
Fort Worth, TX 76101

Mr. William Schweikhard
Kohlman Systems Research
Vice President-Flight Test
319 Perry Street
Lawrence, KS 66044

Mr. William White
FAA; ANE-173
Systems & Equipment Branch
181 South Franklin Avenue
Valley Stream, NY 11581

Mrs. Deborah Mayer
ARINC Research Corp.
2551 Riva Road
Annapolis
MD 21401

Mr. Frederick G. Jenkins
FAA; ANM-130L
Mech/Env & Crashworth. Sec
4344 Donald Douglas Drive
Long Beach, CA 90808

Mr. Hal W. Ferris
FAA; ACE-140C
Propulsion Branch
2300 East Devon Avenue
Des Plaines, IL 60018

Mr. Herbert H. Schoech
FAA; ANM-160L
Flight Test Branch
4344 Donald Douglas Drive
Long Beach, CA 90808

Mr. Jack Acampora
FAA; ANM-174W
Propulsion Section
15000 Aviation Boulevard
Hawthorne, CA 90261

Mr. James D. Erickson
FAA; AWS-170
Helicopter Cert. Branch
P.O. Box 1689
Fort Worth, TX 76101

Mr. James M. Bugbee
FAA; ANM-176W
Flight Test Section
15000 Aviation Boulevard
Hawthorne, CA 90261

Mr. Jay Pardee
FAA; ANE-140
Engine Cert. Office
12 New England Exec. Park
Burlington, MA 01803

Mr. Jim Briscoe
BF Goodrich Aerospace
500 South Main Street
Akron
OH 44318

Mr. Gerald M. Baker
FAA; ACE-160W
Flight Test Branch
1801 Airport Road
Wichita, KS 67209

Mr. Harry Chambers
U.S. Army (AVSCOM)
Attn: DRSAV-ED
4300 Goodfellow Blvd.
St. Louis, MD 63120

Mr. Irwin N. Brumer
FAA; ANE-172
Airframe Branch
181 South Franklin Avenue
Valley Stream, NY 11581

Mr. Jack C. Bentley
FAA; ACE-120A
Airframe Branch
1075 Innerloop Road
College Park, GA 30337

Mr. James G. Plackis
FAA; ANE-176
Flight Test Branch
181 South Franklin Avenue
Valley Stream, NY 11581

Mr. James W. Hart
FAA; ANM-120S
Airframe Branch
17900 Pacific Highway S.
Seattle, WA 98168

Mr. Jess Lewis
FAA; ACE-111
Policy & Guidance Section
601 East 12th Street
Kansas City, MI 64106

Mr. John E. Tigue
FAA; ANE-141
Transport Engine Branch
12 New England Exec. Park
Burlington, MA 01803

Helicopter Association Int
1619 Duke Street
Alexandra
VA 22314-3406

Francis S. Cardone
FAA; ANM-173W
Systems & Equipment Sectio
15000 Aviation Boulevard
Hawthorne, CA 90261

Mr. Andrew Peterson
Boeing Vertol Company
P.O. Box 13858
Philadelphia
PA 19142

Mr. Author J. Pidgeon
FAA; ANE-150
Boston ACO
12 New England Exec. Park
Burlington, MA 01803

Mr. Calvin L. Stoner
FAA; AWS-150
Airplane Certification Br.
P.O. Box 1683
Fort Worth, TX 76101

Mr. Chris Christie
FAA; AEU-100
Brussels A/C Cert. Staff
c/o American Embassy, APO
New York, NY 09667-1011

Mr. Dale V. Vassalli
FAA; ACE-130W
Systems & Equipment Branch
1801 Airport Road
Wichita, KS 67209

Mr. Daumants Belte
U.S. Army AEFA
Edwards AFB
CA 93523

Dr. Kenneth Korkan
Texas A & M University
College of Engineering
College Station, TX 77840

Mr. Al Hubler
FAA-PHL FSDO
PHL International Airport
Bldg. 1 Cargo Area
Philadelphia, PA 19153

Mr. Arnvid V. Rasmussen
FAA; ANM-130S
Systems & Equipment Br.
17900 Pacific Highway S.
Seattle, WA 98168

Mr. Bill Gaitshill
U.S. Army (AVSCOM)
4300 Goodfellow Blvd.
St. Louis
MO 63120

Mr. Charles Smalley
FAA; ACE-130C
Systems & Equipment Branch
2300 East Devon Avenue
Des Plaines, IL 60018

Mr. Curtis Jackson
FAA; ACE-120A
Airframe Branch
1075 Innerloop Road
College Park, GA 30337

Mr. Daniel Salvano
FAA; ANE-100N
A/C Certification Div.
12 New England Exec. Park
Burlington, MA 01803

Mr. David G. Hmiel
FAA; ANM-190S
A/C Modification Branch
17900 Pacific Highway S.
Seattle, WA 98168

Mr. Ronald L. Vavruska
FAA; ANE-153
Systems&Propulsion Branch
12 New England Exec. Park
Burlington, MA 01803

Mr. Terry Barnes
FAA; ANM-105
Seattle ACO
17900 Pacific Highway S.
Seattle, WA 98168

Mr. Thomas Swift
FAA; ANM-100L
Los Angeles ACO
4344 Donald Douglas Drive
Long Beach, CA 90808

Mr. John J. Shapley
FAA; AWS-110
Heli. Policy & Proc. Staff
P.O. Box 1689
Fort Worth, TX 76101

Mr. Joseph Soderquist
FAA; AWS-103
Office of Airworthiness
800 Independence Ave., SW
Washington, DC 20591

Mr. Lloyd L. Edwards
FAA; ACE-140W
Propulsion Branch
1801 Airport Road
Wichita, KS 67209

Mr. Russ Lawton
AOPA Air Safety Foundation
421 Aviation Way
Frederick
MD 21701

Mr. Thomas D. Moreland
FAA; ANM-140S
Propulsion Branch
17900 Pacific Highway S.
Seattle, WA 98168

Mr. Tom Swift
FAA Los Angeles ACO
ANM-101N
4344 Donald Douglas Drive
Long Beach, CA 90808

Mr. Jon E. Hannan
FAA; ACE-160C
Flight Test Branch
2300 East Devon Avenue
Des Plaines, IL 60018

Mr. Kenneth Payauys
FAA; ACE-120C
Airframe Branch
2300 East Devon Avenue
Des Plaines, IL 60018

Mr. Mark I. Quam
FAA; ANM-112
Regulations Branch
17900 Pacific Highway S.
Seattle, WA 98168